CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

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CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

3.1 INTRODUCTION

This chapter provides a profile of the residential clothes dryer and room air conditioner industries in the United States. The U.S. Department of Energy (DOE) developed the market and technology assessment presented in this chapter primarily from publicly available information. This assessment is helpful in identifying the major manufacturers and their product characteristics, which form the basis for the engineering and the life-cycle cost (LCC) analyses. Present and past industry structure and industry financial information help DOE in the process of conducting the manufacturer impact analysis.

3.2 PRODUCT DEFINITIONS

DOE defines "**electric clothes dryer**" under the Energy Policy and Conservation Act (EPCA) of 1975, Pub. L. 94-163, (42 United States Code (U.S.C.) 6291–6309) as "a cabinet-like appliance designed to dry fabrics in a tumble-type drum with forced air circulation. The heat source is electricity and the drum and blower(s) are driven by an electric motor(s)." Similarly, EPCA defines "**gas clothes dryer**" as "a cabinet-like appliance designed to dry fabrics in a tumble-type drum with forced air circulation. The heat source is gas and the drum and blower(s) are driven by an electric motor(s)." (10 Code of Federal Regulation (CFR) 430.2)

DOE defines "**room air conditioner**" under EPCA as "a consumer product, other than a "packaged terminal air conditioner", which is powered by a single phase electric current and which is an encased assembly designed as a unit for mounting in a window or through the wall for the purpose of providing delivery of conditioned air to an enclosed space. It includes a prime source of refrigeration and may include a means for ventilating and heating." (10 CFR 430.2)

3.3 PRODUCT CLASSES

DOE has established separate product classes for each product (residential clothes dryers and room air conditioners). DOE formulates a separate energy conservation standard for each product class. As required by EPCA, the criteria for separation into different classes are: (1) type of energy used, or (2) capacity or other performance-related features such as those that provide utility to the consumer or others deemed appropriate by the Secretary that would justify the establishment of a separate energy conservation standard. (42 U.S.C. 6295 (q) and 6316(a))

For residential **clothes dryers**, DOE considered four product classes for vented and two product classes for ventless dryers, as shown in Table 3.3.1. This is a new analytical structure for clothes dryers, recognizing the unique utility that ventless clothes dryers offer to consumers.[a] Another new entry with unique utility is the combination washer/dryer (*i.e.*, a device which washes and then dries clothes in the same basket/cavity in a combined cycle). Combination washer/dryers are very popular in space-constrained environments (*e.g.*, apartments, recreational vehicles), and all products of this type appear to utilize ventless operation. Thus, like other ventless dryers, such combination washer/dryers can be installed in locations where venting dryers would be precluded due to venting restrictions. As discussed in section 0, DOE published a test procedure final rule amending the DOE test procedure for clothes dryers to include provisions for testing of ventless clothes dryers. Therefore, DOE included product classes for ventless clothes dryers in this rulemaking analysis.

Table 3.3.1 Residential Clothes Dryer Product Classes

Vented dryers
1. Electric, Standard (4.4 cubic feet (ft^3) or greater capacity)
2. Electric, Compact (120 volts (V)) (less than 4.4 ft^3 capacity)
3. Electric, Compact (240 V) (less than 4.4 ft^3 capacity)
4. Gas
Ventless dryers
5. Electric, Compact (240 V) (less than 4.4 ft^3 capacity)
6. Electric, Combination Washer/Dryer

For **room air conditioners**, amendments to EPCA in the National Appliance Energy Conservation Act of 1987 (NAECA), Pub. L. 100-12, initially specified 12 product classes which were applicable to units designed for single- or double-hung window installation or through-the-wall installation and based on the following criteria: (1) cooling capacity; (2) the presence of louvered sides (LS); and (3) the capability of reverse cycle (*i.e.*, the unit can function as a heat pump). (42 U.S.C. 6295(c)(1)) Capacity is measured in British Thermal Units (Btu) per hour (h). In the final rule published in the *Federal Register* on September 24, 1997, DOE established an updated set of performance standards (effective October 1, 2000) which included four additional product classes.[b]

For this final rule, DOE will split product classes 5 and 8 into two product classes each. Current product class 5 (louvered, non-reverse-cycle, capacity of 20,000 and higher) will be split into product class 5A (louvered, non-reverse-cycle, capacity of 20,000 to 27,999 Btu/h) and

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[a] Previously, DOE has described ventless dryers as condensing dryers. The new designation reflects the actual consumer utility (*i.e.,* no external vent required) and the market availability of vented dryers that also condense.

[b] DOE divided the product class covering units with reverse cycle and with louvered sides into units of capacity less than 20,000 Btu/h and units 20,000 Btu/h or more. DOE split the product class covering units with reverse cycle and without louvered sides into units of capacity less than 14,000 Btu/h and units 14,000 Btu/h or more. In addition, DOE established two new product classes for units that are designed to be installed in casement-slider and casement-only windows. Due to the size constraints imposed by casement windows, casement units are small in size and typically deliver 5,000 to 10,000 Btu/h in cooling capacity.

product class 5B (Louvered, non-reverse-cycle, capacity of 28,000 and higher). Product class 8 (non-louvered, non-reverse-cycle, capacity of 8,000 to 13,999 Btu/h) will be split into product class 8A (non-louvered, non-reverse-cycle, capacity of 8,000 to 10,999 Btu/h) and 8B (non-louvered, non-reverse-cycle, capacity of 11,000 to 13,999 Btu/h). These product class changes are discussed in greater detail in section 5.9.2.11 in chapter 5 of this technical support document (TSD). Table 3.3.2 lists the 18 product classes for room air conditioners.

Table 3.3.2 Room Air Conditioner Product Classes

Without reverse cycle and with louvered sides
1. Less than 6,000 Btu/h
2. 6,000 to 7,999 Btu/h
3. 8,000 to 13,999 Btu/h
4. 14,000 to 19,999 Btu/h
5A. 20,000 to 27,999 Btu/h
5B. 28,000 Btu/h or more
Without reverse cycle and without louvered sides
6. Less than 6,000 Btu/h
7. 6,000 to 7,999 Btu/h
8A. 8,000 to 10,999 Btu/h
8B. 11,000 to 13,999 Btu/h
9. 14,000 to 19,999 Btu/h
10. 20,000 Btu/h or more
With reverse cycle
11. With louvered sides and less than 20,000 Btu/h
12. Without louvered sides and less than 14,000 Btu/h
13. With louvered sides and 20,000 Btu/h or more
14. Without louvered sides and 14,000 Btu/h or more
Casement
15. Casement-Only
16. Casement-Slide

3.4 PRODUCT TEST PROCEDURES

Test procedures exist for both products covered by this rulemaking to determine energy efficiency and annual energy use as the basis for representation and determination of compliance with energy conservation standards. DOE established test procedures for residential clothes dryers and room air conditioners through the rulemaking process, in both cases over 25 years ago. The Energy Independence and Security Act of 2007 (EISA 2007), Pub. L. 110-140, amends EPCA to require DOE to review these test procedures at least every 7 years and to amend them if such amended test procedures would more accurately or fully comply with the requirements of producing test results which measure energy efficiency, energy use, or estimated annual operating cost during a representative average use cycle or period of use without being unduly burdensome to conduct. (42 U.S.C. 6293(b)(1))

DOE originally established its test procedure for residential **clothes dryers** in a final rule published in the *Federal Register* on September 14, 1977. (42 FR 46145; 10 CFR part 430, subpart B, appendix D) On May 19, 1981 DOE published a final rule to amend the test procedure by establishing a field-use factor for clothes dryers with automatic termination controls, clarifying the test cloth specifications and clothes dryer preconditioning, and making editorial and minor technical changes. 46 FR 27324. The clothes dryer test procedure cited two industry test standards: (1) the Association of Home Appliance Manufacturers (AHAM) Standard HLD-1-1974, *AHAM Performance Evaluation Procedure for Household Tumble Type Clothes Dryers* and (2) AHAM Standard HLD-2EC, *Test Method for Measuring Energy Consumption of Household Tumble Type Clothes Dryers*, December 1975.

DOE redesignated and amended its test procedure for **room air conditioners** on June 29, 1979. (44 FR 37938; 10 CFR part 430, subpart B, appendix F) The current room air conditioner test procedure cites two test standards that are each at least 25 years old: (1) American National Standards (since renamed American National Standards Institute (ANSI)) Z234.1-1972, Room *Air Conditioners* and (2) American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 16-69, *Method of Testing for Rating Room Air Conditioners*.

Standby power measurement is not currently incorporated into DOE test procedures for residential clothes dryers or room air conditioners. Section 310 of EISA 2007 amended Section 325 of EPCA to require that the test procedures for clothes dryers and room air conditioners be amended to include measurement of standby mode and off mode power, taking into consideration the most current version of International Electrotechnical Commission (IEC) Standard 62301 *Household electrical appliances – Measurement of standby power* (IEC Standard 62301).[c] EPCA, as amended by EISA 2007, also required that the final rule for this test procedure be published no later than March 31, 2009. (42 U.S.C. 6295(gg)) DOE initiated a separate test procedure rulemaking to modify the test procedures for clothes dryers and room air conditioners to provide procedures for the measurement of standby and off modes. DOE published a NOPR for this rule on December 9, 2008 (December 2008 TP NOPR). 73 FR 74639.

DOE determined after the December 2008 TP NOPR was published that it would consider a revised version of IEC Standard 62301, *i.e.*, IEC Standard 62301 Second Edition, which at that time was expected to be published in July 2009. DOE anticipated, based on review of drafts of the updated IEC Standard 62301, that the revisions could include different mode definitions. Subsequently, DOE received information that IEC Standard 62301 Second Edition

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[c] DOE notes that EPCA as amended by EISA 2007, also requires DOE to consider IEC Standard 62087, which specifies methods of measurement for the power consumption of TV receivers, VCRs, set top boxes, audio equipment and multi-function equipment for consumer use. IEC Standard 62087 does not, however, include measurement for the power consumption of electrical appliances such as clothes dryers and room air conditioners. Therefore, DOE determined that IEC Standard 62087 was not suitable for amendments to the clothes dryer and room air conditioner test procedures.

would not be published until late 2010. To allow for the consideration of standby and off mode power consumption in this energy conservation standards rulemaking, DOE published a SNOPR on June 29, 2010 (June 2010 TP SNOPR), proposing mode definitions based on the new mode definitions from the most recent draft version of IEC Standard 62301 Second Edition which, at that time, was designated as IEC Standard 62301 Second Edition Committee Draft for Vote (IEC Standard 62301 CDV). 75 FR 37594. The IEC circulated IEC Standard 62301 CDV on August 28, 2009. IEC Standard 62301 CDV contained the most recent proposed amendments to IEC Standard 62301, including new mode definitions, at the time the June 2010 TP SNOPR was issued. IEC Standard 62301 CDV revised the proposed mode definitions from previous draft versions of IEC Standard 62301 and addressed comments received by interested parties in response to those drafts. As a result, DOE stated in the June 2010 TP SNOPR that the mode definitions in IEC Standard 62301 CDV represent the best definitions available for the supporting analysis. Id.

DOE also determined after publication of the December 2008 TP NOPR to conduct a rulemaking to amend the active mode test procedure for clothes dryers and room air conditioners. DOE addressed the test procedure issues relating to active mode for clothes dryers and room air conditioners in the June 2010 TP SNOPR. In the June 2010 TP SNOPR, DOE proposed the following test procedure amendments for the measurement of active mode energy consumption for clothes dryers and room air conditioners: 1) procedures for more accurately measuring the effects of different automatic termination technologies in clothes dryers; (2) provisions for ventless clothes dryers, which are being considered under an amended energy conservation standard; (3) updated detergent specifications for clothes dryer test cloth preconditioning; (4) changes to better reflect current usage patterns and capabilities for the covered products; (5) updated references to external test procedures; and (6) clarifications to the test conditions for gas clothes dryers. 75 FR 37594 (June 29, 2010).

DOE recently published a final rule in the *Federal Register* on January 6, 2011, (January 2011 TP Final Rule) in which it adopted amendments to the clothes dryer and room air conditioner test procedures. 76 FR 972. In the January 2011 TP Final Rule, DOE incorporated by reference into both the clothes dryer and room air conditioner test procedures specific clauses from IEC Standard 62301 First Edition 2005-06 regarding test conditions and test procedures for measuring standby and off mode power consumption. DOE also incorporated into each test procedure definitions of "active mode," "standby mode," and "off mode" that are based on the definitions provided in IEC Standard 62301 CDV. Further, DOE adopted language in each test procedure to clarify the application of clauses from IEC Standard 62301 First Edition and the mode definitions from IEC Standard 62301 CDV for measuring standby and off mode power consumption. 76 FR 972, 979–987 (Jan. 6, 2011).

DOE also notes that EISA 2007 amended EPCA to require that standby mode and off mode energy consumption be integrated into the overall energy efficiency, energy consumption, or other energy descriptor unless the Secretary determines that – (i) the current test procedures for a covered product already fully account for and incorporate standby mode and off mode energy consumption of the covered product; or (ii) such an integrated test procedure is technically infeasible for a particular covered product, in which case the Secretary shall prescribe a separate standby mode and off mode energy use test procedure for the covered product, if technically feasible. (42 U.S.C. 6295(gg)(2)(A)) For both clothes dryers and room air conditioners, DOE determined in the January 2011 TP Final Rule that it is technically feasible to incorporate standby mode and off mode energy consumption into overall energy consumption. As a result, DOE adopted new methods to calculate clothes dryer and room air conditioner standby and off mode energy use and a new measure of energy efficiency (Combined Energy Factor (CEF) and Combined Energy Efficiency Ratio (CEER), respectively) that integrates standby and off mode energy use with the active mode energy use for both products. 76 FR 972, 991–992 (Jan. 6, 2011). Accordingly, DOE developed the amended energy conservation standards for residential clothes dryers and room air conditioners based on these integrated metrics.

Concerning the active mode, DOE adopted amendments in the January 2011 TP Final Rule to the clothes dryer test procedure to include the provisions for testing ventless clothes dryers proposed in the June 2010 TP SNOPR. These amendments consisted of adding separate definitions for a "conventional clothes dryer" (vented) and a "ventless clothes dryer". Further, the alternate test procedure qualifies the requirement for an exhaust simulator so that it would only apply to conventional clothes dryers. DOE also adopted provisions to clarify the testing procedures for ventless clothes dryers, including requirements for clothes dryers equipped with a condensation box, requirements for the condenser heat exchanger, and specifications for ventless clothes dryer preconditioning. In addition to the amendments proposed in the June 2010 TP SNOPR, DOE adopted clarifications in the January 2011 TP Final Rule to provide explicit instructions as to the procedure for re-running the test cycle when the condensation box is full. DOE also revised the requirement for ventless clothes dryer preconditioning to remove the maximum time limit for achieving a steady-state temperature. DOE also included additional editorial clarifications to the testing procedures for ventless clothes dryers. 76 FR 972, 1003–09 (Jan. 6, 2011).

In addition, DOE amended the clothes dryer test procedure to reflect current usage patterns and capabilities. These amendments were based on DOE's analysis of consumer usage patterns data. DOE revised the number of annual use cycles from 416 cycles per year to 283 cycles per year for all types (*i.e.*, product classes) of clothes dryers. This revision was based on DOE's analysis of data from the Energy Information Administration (EIA)'s 2005 *Residential Energy Consumption Survey* (RECS)[d],[e] for the number of laundry loads (clothes washer cycles) washed per week and the frequency of clothes dryer use. In the June 2010 TP SNOPR, DOE proposed to revise the 70-percent initial remaining moisture content (RMC) required by the test procedure to 47 percent so as to accurately represent the condition of laundry loads after a wash cycle. This proposal was based on analysis of shipment-weighted RMC data for clothes washers submitted by the Association of Home Appliance Manufacturers (AHAM) and based on a distribution analysis of RMC values for clothes washer models listed in the December 22, 2008,

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[d] U.S. Department of Energy-Energy Information Administration. *Residential Energy Consumption Survey*, 2005 Public Use Data Files, 2005. Washington, DC. Available online at: http://www.eia.doe.gov/emeu/recs/

[e] EIA's 2005 RECS is the latest available version of this survey.

California Energy Commission (CEC) directory. 75 FR 37594, 37599 (June 29, 2010). Based on comments from interested parties, DOE determined that an initial clothes dryer RMC of 57.5 percent more accurately represents the moisture content of laundry loads after a wash cycle for the purposes of clothes dryer testing. This RMC was derived from the 47-percent shipment-weighted RMC for clothes washers, but was derived without applying an RMC correction factor as required by the DOE clothes washer test procedure. For these reasons, DOE revised the initial clothes dryer RMC from 70 percent to 57.5 percent in the final rule. In addition, DOE changed the 7-pound (lb) clothes dryer test load size specified by the current test procedure for standard-size clothes dryers to 8.45 lb. This revision was based on the historical trends of clothes washer tub volumes and the corresponding percentage increase in clothes washer test load sizes (as specified by the DOE clothes washer test procedure). DOE assumed these historical trends proportionally impact dryer load sizes. 76 FR 972, 1010–15 (Jan. 6, 2011).

Based on the rinse temperature use factors in the DOE clothes washer test procedure and 2005 RECS data reporting the percentage of clothes washer cycles for which consumers use cold water for the rinse cycle, DOE amended the clothes dryer test procedure to change the water temperature for clothes dryer test load preparation from 100 degrees Fahrenheit (°F) ± 5°F to 60°F ± 5°F. This temperature is more representative of the clothes load temperature after a cold rinse cycle at the end of the wash cycle. 76 FR 972, 995-997 (Jan. 6, 2011).

DOE also amended the clothes dryer test procedure to: (1) revise the detergent specifications for test cloth preconditioning due to obsolescence of the detergent specified in the test procedure, (2) update the reference to the industry test standard, (3) eliminate an unnecessary reference to an obsolete industry clothes dryer test standard, (4) amend the provisions in its test procedure which specify test conditions for gas clothes dryers to clarify the required gas supply pressure, (5) amend the provisions for measuring the drum capacity, (6) amend the provisions for the application of the field use factor for automatic cycle termination, and (7) add the calculations of energy factor (EF) and CEF to 10 CFR part 430, subpart B, appendix D1. 76 FR 972, 994, 1009–10, 1017–19 (Jan. 6, 2011).

In the June 2010 TP SNOPR, DOE proposed amendments to more accurately measure automatic cycle termination by accounting for the amount over-drying energy consumption. 75 FR 37594, 37599 (June 29, 2010). However, DOE conducted testing of representative clothes dryers using the automatic cycle termination test procedure proposed in the June 2010 TP SNOPR. The test results showed that all of the dryers tested significantly over-dried the DOE test load to near bone dry. In addition, the measured EF values were significantly lower than EF values obtained using the existing DOE test procedure, and the test data indicated that clothes dryers equipped with automatic termination controls were less efficient than timer dryers. DOE stated in the January 2011 TP Final Rule that the test procedure amendments for automatic cycle termination proposed in the June 2010 TP SNOPR do not adequately measure the energy consumption of clothes dryers equipped with such systems using the test load specified in the DOE test procedure. DOE believes that clothes dryers with automatic termination sensing control systems, which infer the RMC of the load from the properties of the exhaust air such as temprature and humidity, may be designed to stop the cycle when the consumer load has a higher RMC than the RMC obtained using the proposed automatic cycle termination test procedure in conjunction with the existing test load.[f] Manufacturers have indicated, however, that test load types and test cloth materials different than those specified in the DOE test procedure do not produce results as repeatable as those obtained using the test load as currenty specified. In addition, DOE presented data in the May 1981 TP Final Rule from a field use survey conducted by AHAM as well as an analysis conducted by the National Bureau of Standards (now known as the National Institute of Standards and Technology (NIST)) of field test data on automatic termination control dryers. Analysis of this data showed that clothes dryers equipped with an automatic cycle termination feature consume less energy than timer dryers by reducing over-drying. 46 FR 27324 (May 19, 1981). For these reasons, DOE stated in the January 2011 TP Final Rule that the test procedure amendments for automatic cycle termination proposed in the June 2010 TP SNOPR do not adequately measure the energy consumption of clothes dryers equipped with such systems. As a result, DOE did not adopt the amendments for automatic cycle termination proposed in the June 2010 TP SNOPR. 76 FR 972, 993–1003 (Jan. 6, 2011).

Also as part of the January 2011 TP Final Rule, DOE amended the room air conditioner test procedure to update the references to the industry test standards to reference, ANSI/AHAM RAC-1-2008, *Room Air Conditioners*, and ANSI/ASHRAE 16-1983 (RA2009), *Method of Testing for Rating Room Air Conditioners and Packaged Terminal Air Conditioners*, respectively. 76 FR 972, 1016–1017 (Jan. 6, 2011).

In the October 24, 2007 Framework Document, DOE identified two other limitations of the room air conditioner test procedure: (1) the inability of the test procedure to measure the benefits of technologies that improve part-load performance, and (2) the assumed annual operational hours.

The current room air conditioner test procedure measures only the full-load performance at outdoor ambient conditions of 95 ºF dry-bulb and 75 ºF wet-bulb. Therefore, technologies that improve part-load performance, such as multiple-speed compressors and variable-opening expansion devices, will not improve the rated performance of a room air conditioner under the current test procedure. In contrast, central air conditioners and heat pumps are rated with a seasonal energy efficiency ratio (SEER) descriptor, but the test procedure consists of multiple rating points that add time and expense when rating the product.

DOE concluded in the June 2010 TP SNOPR that widespread use of part-load technology in room air conditioners would not likely be stimulated by the development of a part-load metric at this time, and therefore, the significant effort required to develop an accurate part-load metric is not likely to be warranted by the expected minimal energy savings. 75 FR 37594, 37633–34

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[f] To investigate this, DOE conducted additional testing using a test load similar to that specified in AHAM Standard HLD-1-2009, which consists of cotton bed sheets, towels, and pillow cases. For tests using the same automatic cycle termination settings as were used in the testing described earlier (i.e., normal cycle setting and highest temperature setting, the alternate test load was dried to 1.7 to 2.2 percent final RMC, with an average RMC of 2.0 percent. In comparison, the same clothes dryer under the same cycle settings dried the DOE test load to 0.3 to 1.2 percent RMC, with an average RMC of 0.7 percent. Thus, DOE concluded that the proposed automatic cycle termination control test procedures may not stop at an appropriate RMC when used with the current test load.

(June 29, 2010). DOE also noted that the key design changes that improve full-load efficiency also improve part-load efficiency, so the existing EER metric is already a strong indication of product efficiency over a wide range of conditions. DOE concluded that development of an additional test for part load, or a change of the room air conditioner metric to a part-load test, is not supported by information available to DOE at this time. Therefore, DOE did not consider amendments to its room air conditioner test procedure to measure part-load performance in the June 2010 TP SNOPR. 75 FR 37594, 37634 (June 29, 2010).For these reasons, DOE did not amend its room air conditioner test procedure to measure part-load performance in the January 2011 TP Final Rule. 76 FR 972, 1016 (Jan. 6, 2011).

DOE determined in the January 2011 TP Final Rule that the 750 annual operating hours specified by the current DOE room air conditioner test procedure is representative of current usage patterns, based upon its analysis of data from the 2005 RECS. Therefore, DOE did not amend the annual usage hours specified by the current DOE test procedure for room air conditioners. 76 FR 972, 1015–16 (Jan. 6, 2011).

EPCA requires that DOE must determine to what extent, if any, the proposed test procedure would alter the measured energy efficiency of any covered product as determined under the existing test procedure. (42 U.S.C. 6293(e)(1)) If DOE determines that the amended test procedure would alter the measured efficiency of a covered product, DOE must amend the applicable energy conservation standard during the rulemaking carried out with respect to such test procedure. In determining the amended energy conservation standard, the Secretary shall measure, pursuant to the amended test procedure, the energy efficiency, energy use, or water use of a representative sample of covered products that minimally comply with the existing standard. (42 U.S.C. 6293(e)(2))

Under 42 U.S.C. 6295(gg)(2)(C), EPCA provides that amendments to the test procedures to include standby mode and off mode energy consumption will not determine compliance with previously established standards. (U.S.C. 6295(gg)(2)(C)) Because the amended test procedures for standby mode and off mode energy consumption would not alter existing measures of energy consumption or efficiency, these amendments would not affect a manufacturer's ability to demonstrate compliance with previously established standards.

As discussed in chapter 5 of this TSD, DOE investigated how the amendments to the active mode provisions in its clothes dryer and room air conditioner test procedures in the January 2011 TP Final Rule affect the measured efficiency of products.

3.5 MANUFACTURER TRADE GROUPS

DOE recognizes the importance of trade groups in disseminating information and promoting the interests of the industry that they support. To gain insight into the residential clothes dryer and room air conditioner industries, DOE researched various associations available to manufacturers, suppliers, and users of such equipment. DOE also used the member lists of these groups in the construction of an exhaustive database containing domestic manufacturers.

DOE identified several trade groups that support, or have an interest in, the residential clothes dryer and/or room air conditioner industries, including AHAM and the Air Conditioning and Refrigeration Institute.

3.5.1 Association of Home Appliance Manufacturers

AHAM[g], formed in 1967, aims to enhance the value of the home appliance industry through leadership, public education and advocacy. AHAM provides services to its members including government relations; certification programs for room air conditioners, dehumidifiers and room air cleaners; an active communications program; and technical services and research. In addition, AHAM conducts other market and consumer research studies and publishes a biennial *Major Appliance Fact Book*. AHAM also develops and maintains technical standards for various appliances to provide uniform, repeatable procedures for measuring specific product characteristics and performance features.

3.5.2 Air Conditioning, Heating, and Refrigeration Institute

The Air Conditioning, Heating, and Refrigeration Institute (AHRI)[h] is the trade organization that represents manufacturers of over 90 percent of the air conditioning and refrigeration equipment that is currently installed in the United States. AHRI develops and publishes technical standards, often in conjunction with ANSI, the IEC, and the International Organization for Standardization (ISO). AHRI maintains a certification program and certified product database, and supports legislation, regulations, and codes favorable to the HVACR industry. While AHRI does not certify room air conditioners, it represents a number of manufacturers which produce multiple types of air conditioning systems, including room air conditioners, and is involved with regulatory issues affecting all types of refrigeration-based systems.

3.6 MANUFACTURER INFORMATION

The following section details information regarding manufacturers of residential clothes dryers and room air conditioners for sale in the United States, including estimated market shares (section 3.6.1), industry mergers and acquisitions (section 3.6.2), potential small business impacts (section 3.6.3), and product distribution channels (section 3.6.4).

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[g] For more information, please visit www.aham.org.

[h] For more information, please visit http://www.ahrinet.org/

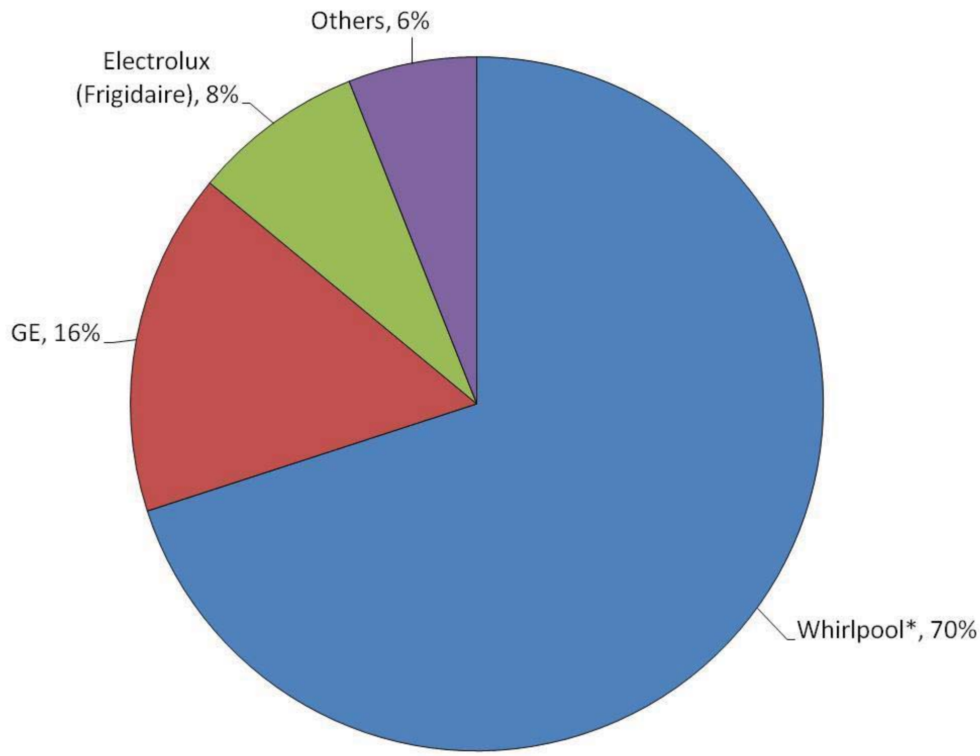
3.6.1 Manufacturers and Market Shares

Using publicly available data (*e.g. Appliance Magazine* and market assessments done by third parties), DOE estimates the market shares for domestic manufacturers of each of the two products contained in this standards rulemaking. Manufacturers may offer multiple brand names. Some of the brand names come from independent appliance manufacturers which have been acquired over time, and domestic manufacturers may put their brand on a product manufactured overseas. Companies included in this analysis may also be off-shore manufacturers that maintain a significant domestic presence via a U.S. entity.

For residential **clothes dryers**, DOE estimates that there are 14 manufacturers selling into the domestic market, of which several are foreign-owned companies with manufacturing facilities outside of the United States. The majority of market share is held by four major domestic manufacturers, including Whirlpool Corporation (Whirlpool), Maytag Corporation (Maytag), GE Consumer & Industrial (GE), and AB Electrolux (Frigidaire).[1] As will be discussed in section 3.6.2, Maytag and Whirlpool merged in 2006 but have continued to maintain both product lines to this date. The combined Maytag-Whirlpool entity accounts for 70 - 74 percent of the residential clothes dryer market. Other manufacturers include Alliance Laundry Systems LLC (Alliance), AM Appliance Group (formerly ASKO, Inc.), BSH Home Appliances Corporation (Bosch-Siemens), Fisher & Paykel Appliances Limited (Fisher & Paykel), Haier America Trading, LLC (Haier), Indesit Company (Indesit), LG Electronics, Inc. (LG), Miele, Inc. (Miele), Samsung Electronics America, Inc. (Samsung), and Felix Storch, Inc. (Summit). Table 3.6.1 lists these manufacturers. Figure 3.6.1 and Figure 3.6.2 illustrate the 2008 market shares for the domestic residential electric and gas clothes dryer markets, respectively.

Table 3.6.1 Major and Other Residential Clothes Dryer Manufacturers

Major Manufacturers	Other Manufacturers
Whirlpool	Alliance
Maytag	ASKO
GE	Bosch-Siemens
Frigidaire	Fisher & Paykel
	Haier
	Indesit
	LG
	Miele
	Samsung
	Summit



*Whirlpool share of market in 2008 includes Maytag

Figure 3.6.1 2008 Market Shares for the Domestic Electric Clothes Dryer Market[2]

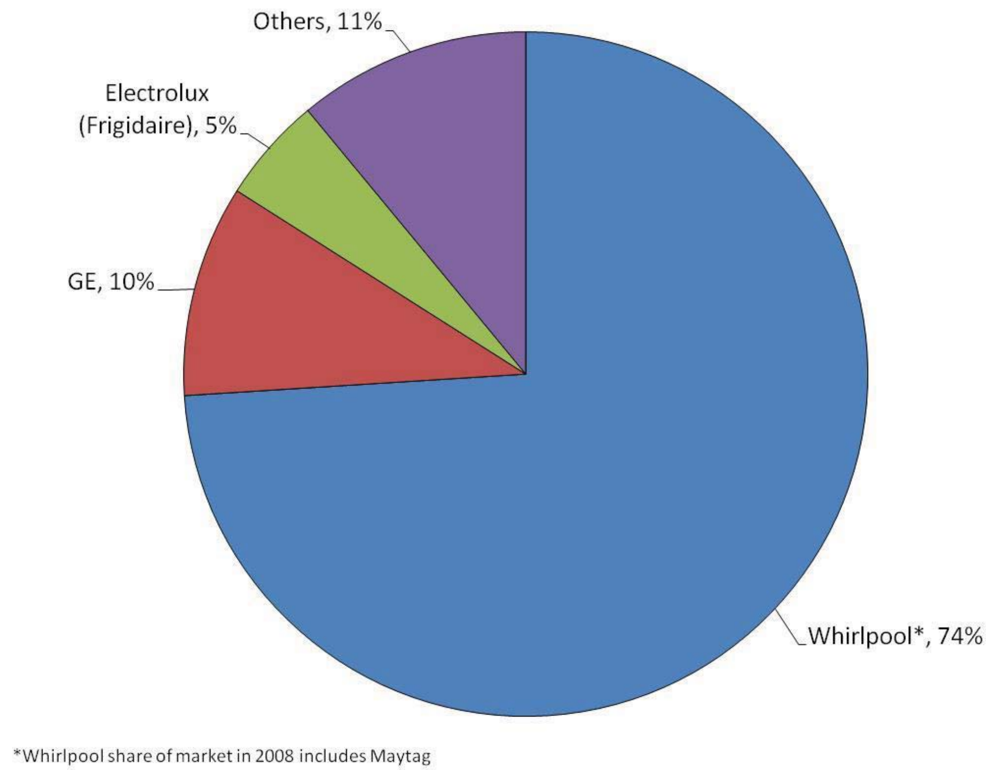


Figure 3.6.2 2008 Market Shares for the Domestic Gas Clothes Dryer Market[3]

Table 3.6.2 and Table 3.6.3 show the market share for electric and gas clothes dryer manufacturers, respectively, between 2000 and 2008. The market shares for the top three clothes dryer manufacturers have remained relatively stable since 2000; however, the market share for Electrolux gas dryers has decreased by 5 percent since 2000.

Table 3.6.2 2000-2008 Electric Clothes Dryer Manufacturer Market Share [4]

	Market Share *(%)*								
Company	**2008**	**2007**	**2006**	**2005**	**2004**	**2003**	**2002**	**2001**	**2000**
Whirlpool	70*	56	56	56	56	56	55	54	54
Maytag	-	16	17	18	19	18	20	20	19
GE	16	15	15	14	14	15	17	18	16
Electrolux (Frigidaire)	8	8	9	10	10	11	8	8	8
Others	6	5	3	2	1	0	0	0	3

*Whirlpool share of market in 2008 includes Maytag.

Table 3.6.3 2000-2008 Gas Clothes Dryer Manufacturer Market Share [5]

Company	Market Share (%)								
	2008	**2007**	**2006**	**2005**	**2004**	**2003**	**2002**	**2001**	**2000**
Whirlpool	74	55	55	55	55	55	57	58	56
Maytag	-	22	23	25	25	26	23	23	21
GE	10	11	11	11	11	11	13	13	13
Electrolux (Frigidaire)	5	5	6	7	7	8	7	6	10
Others	11	7	5	3	2	0	0	0	0

*Whirlpool share of market in 2008 includes Maytag.

For **room air conditioners**, DOE estimates that there are less than 10 key manufacturers supplying the U.S. market. Based on data published by *Appliance Magazine*,[6] nearly three quarters of the domestic market, 70 percent, in 2008 was controlled by four manufacturers: LG, Fedders Corporation (Fedders), Frigidaire, and Whirlpool. The remaining market share was divided among companies including Haier, Samsung, Sharp Electronics Corporation (Sharp), Friedrich Air Conditioning Company (Friedrich) and others. Table 3.6.4 lists these manufacturers. Figure 3.6.3 illustrates the 2008 market shares for the domestic room air conditioner market.

Table 3.6.4 Major and Other Room Air Conditioner Manufacturers

Major Manufacturers	Other Manufacturers
LG	Haier
Fedders	Samsung
Frigidaire	Sharp
Whirlpool	Matsushita
	Friedrich
	Carrier

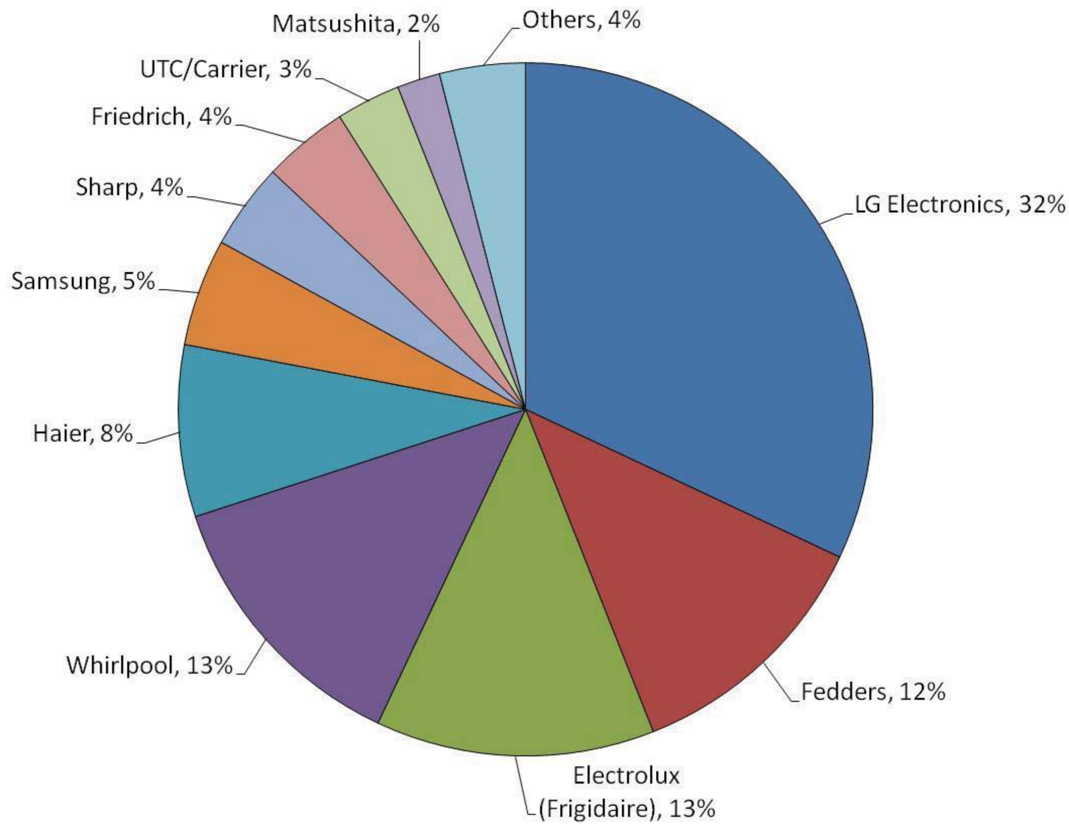


Figure 3.6.3 2008 Market Shares for the Domestic Room Air Conditioner Market[6]

Table 3.6.5 shows the market share for room air conditioner manufacturers between 2000 and 2008. The market share for LG increased 12 percent since 2000, whereas the market share for Fedders and Electrolux dropped by 10 and 4 percent, respectively, over the same period. Whirlpool's market share remained relatively stable between 2000 and 2008.

Table 3.6.5 2000-2008 Room Air Conditioner Manufacturer Market Share [7]

	Market Share *(%)*								
Company	**2008**	**2007**	**2006**	**2005**	**2004**	**2003**	**2002**	**2001**	**2000**
LG Electronics	32	32	30	30	29	32	28	26	20
Fedders	12	12	14	14	22	21	22	20	22
Electrolux (Frigidaire)	13	13	14	14	11	13	11	13	17
Whirlpool	13	13	14	14	11	9	11	12	12
Haier	8	8	6	5	6	9	12	11	6
Samsung	5	5	5	5	6	5	2	1	3
Sharp	4	4	5	4	4	3	4	3	2
Friedrich	4	4	4	4	2	2	3	3	3
UTC/Carrier	3	3	3	0	0	2	2	3	2
Matsushita	2	2	1	2	2	3	2	2	3
Others	4	4	4	8	7	5	3	6	10

Since 2007 there have been significant changes to the market. Fedders and Whirlpool left the market in 2008, and the status of other manufacturers including Sharp and Matsushita is unclear. Also not reflected in the market share data is the distinction between brand share and manufacturer share. GE and Midea, for example, are active brands that are not listed in the *Appliance Magazine* data, while some of the brands listed do not currently manufacture their room air conditioners. The manufacture of room air conditioners has, in recent years, entirely moved offshore. There is some limited manufacturing still occurring in North America, but most of the production is currently in Asia, primarily in China.

3.6.2 Mergers and Acquisitions

Due to mergers and acquisitions, the home appliance industry continues to consolidate. While this phenomenon varies from product to product within the industry, the large market shares of a few companies provide evidence in support of this characterization.

According to the September 2009 issue of *Appliance Magazine*, four manufacturers comprise 85 percent of the core appliance market share. "Core appliances" include dishwashers, dryers, freezers, ranges, refrigerators, and clothes washers. Table 3.6.6 lists these core appliance manufacturers, and Figure 3.6.4 illustrates the breakdown of 2008 market shares in the core appliance category.

Table 3.6.6 Core Appliance Manufacturers

Core Appliance Manufacturers
Whirlpool
GE
Electrolux (Frigidaire)

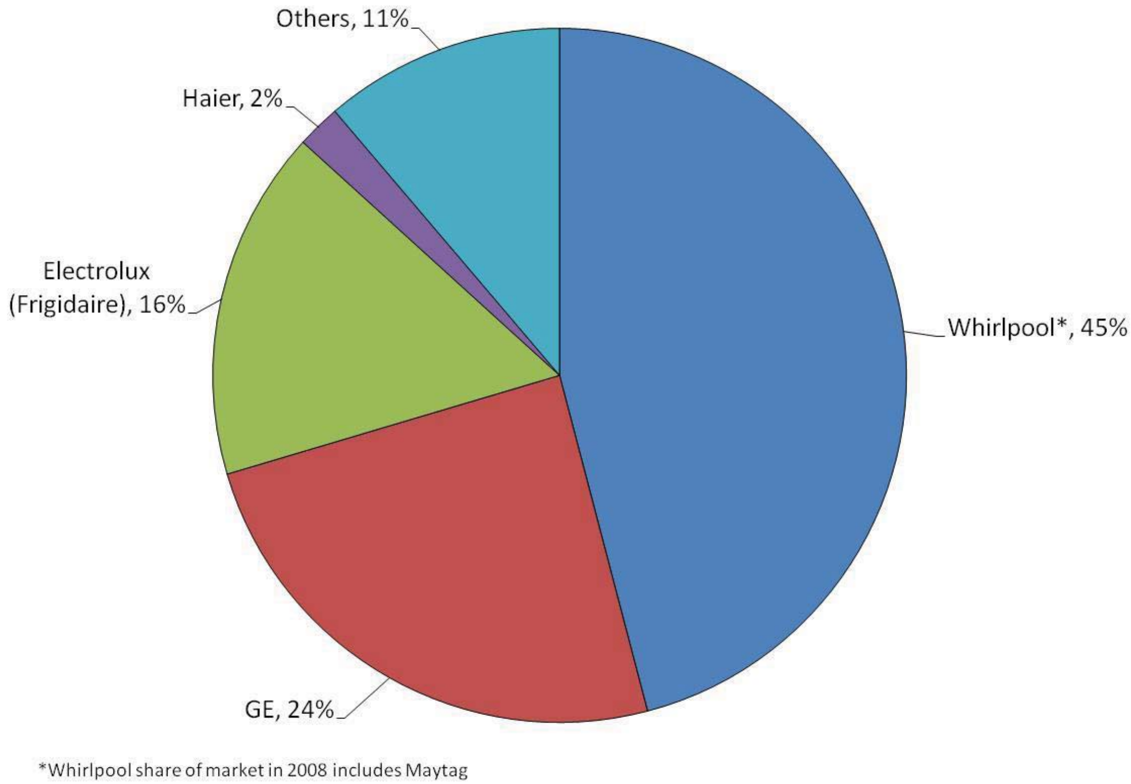


Figure 3.6.4 2008 Core Appliance Market Shares[8]

On August 22, 2005, Whirlpool, headquartered in Benton Harbor, Michigan, and Maytag, based in Newton, Iowa, announced plans to merge in a deal worth $2.7 billion.[9] Maytag shareholders approved the merger on December 22, 2005. Shortly after announcing the merger, Whirlpool submitted a pre-merger notification to the U.S. Department of Justice (DOJ). The DOJ Antitrust Division initiated an investigation, scheduled to end February 27, 2006, into the effects of the merger, including potential lessening of competition or the creation of a monopoly. Following this initial review, the DOJ asked for additional materials from each company and extended the review to March 30, 2006.

Opponents of the merger asserted that the combined companies would control as much as 70 percent of the residential laundry market and as much as 50 percent of the residential dishwasher market.[10] Whirlpool claimed that their large potential residential laundry market share was skewed because the company produces washing machines for Sears, which sells them under their Kenmore in-house brand. Whirlpool went on to say that they must periodically bid with other manufacturers to keep the Kenmore contract and that Sears controls the pricing of the Kenmore units.[11]

In early January 2006, U.S. Senator Tom Harkin and U.S. Representative Leonard Boswell, both of Iowa, called upon the DOJ to block the merger, claiming it would give Whirlpool an unfair advantage in the home appliance industry. The Congressmen wrote, that if the DOJ does not block the deal, the agency should at least "require that Whirlpool divest the washer and dryer portions of Maytag to a viable purchaser who will have the financial capability and desire to continue to operate that business."[12]

On March 29, 2006, DOJ closed its investigation and approved the merger. DOJ claims "that the proposed transaction is not likely to reduce competition substantially. The combination of strong rival suppliers with the ability to expand sales significantly and large cost savings and other efficiencies that Whirlpool appears likely to achieve indicates that this transaction is not likely to harm consumer welfare."[13]

The DOJ Antitrust Division focused its investigation on residential laundry, although it considered impacts across all products offered by the two companies. DOJ determined that the merger would not give Whirlpool excessive market power in the sale of its products and that any attempt to raise prices would likely be unsuccessful. In support of this claim, DOJ noted: (1) other U.S. brands, including Kenmore, GE, and Frigidaire, are well established; (2) foreign manufacturers, including LG and Samsung, are gaining market share; (3) existing U.S. manufacturers are below production capacity; (4) the large home appliance retailers have alternatives available to resist price increase attempts; and (5) Whirlpool and Maytag substantiated large cost savings and other efficiencies that would benefit consumers.[14]

Whirlpool and Maytag completed the merger on March 31, 2006. This large merger follows several other mergers and acquisitions in the home appliance industry. For example, Maytag acquired Jenn-Air Corporation (Jenn-Air) in 1982, Magic Chef, Inc. (Magic Chef) in 1986, and Amana Appliances (Amana) in 2001. Whirlpool acquired the KitchenAid division of Hobart Corporation (KitchenAid) in 1986. White Consolidated Industries (WCI) acquired the Frigidaire division of General Motors Corporation in 1979, and AB Electrolux acquired WCI (and therefore Frigidaire) in 1986.

3.6.3 Small Business Impacts

DOE considers the possibility of small businesses being impacted by the promulgation of energy conservation standards for residential clothes dryers and room air conditioners. The Small Business Association (SBA) considers an entity to be a small business if, together with its affiliates, it employs less than a threshold number of workers specified in 13 CFR part 121, which relies on size standards and codes established by the North American Industry Classification System (NAICS). The threshold number for NAICS classification for 335224, which applies to household laundry equipment manufacturers and includes clothes dryer manufacturers, is 1,000 employees. The threshold number for NAICS classification for 333415, which applies to air conditioning and warm air heating equipment and commercial and industrial refrigeration equipment manufacturers and includes room air conditioner manufacturers, is 750 employees. Searches of the SBA website[i] to identify manufacturers within these NAICS codes

[i] A searchable database of certified small businesses is available online at: http://dsbs.sba.gov/dsbs/search/dsp_dsbs.cfm.

that manufacture clothes dryers and/or room air conditioners revealed only Staber Industries, Inc. (Staber) of Groveport, Ohio, as a producer of laundry equipment. However, DOE notes that the Staber website indicates that their clothes dryer is manufactured by Whirlpool and rebranded. Therefore, DOE believes that there are no clothes dryer manufacturers that are considered a small business. Further, DOE is not aware of any room air conditioner manufacturers that are considered a small business. For any small business manufacturers of the two appliance products that DOE identifies, DOE will study the potential impacts on the small businesses in greater detail during the manufacturer impact analysis (MIA), which it will conduct as a part of the NOPR analysis.

3.6.4 Distribution Channels

Understanding the distribution channels of products covered by this rulemaking is an important facet of the market assessment. DOE gathered information regarding the distribution channels for residential clothes dryers and room air conditioners from publicly available sources. This section contains distribution channel information for residential appliances.

For residential appliances, including room air conditioners and clothes dryers, the majority of consumers purchase their appliances directly from retailers. Table 3.6.7 identifies the types of retail stores through which major appliances, including residential clothes washers, are sold, based on data from the AHAM *Fact Book* 2005.[15]

Table 3.6.7 Major Appliance Sales by Channel (Purchased between 2001 and 2005)[16]

Type of Store	Percentage of Appliance Purchases *(%)*
Department Store (such as Sears or Kohls)	34.7
Appliance Store or Consumer Electronics Store	30.9
Home Improvement Store (such as Lowe's or Home Depot)	23.8
Discount Store (such as Wal-Mart or K-Mart)	2.0
Membership Warehouse Club/Store (such as Sam's or Costco)	1.8
Another type of store	6.8

Home appliance retailers generally obtain products directly from manufacturers. The AHAM *Fact Book* 2003 shows that over 93 percent of residential appliances are distributed from the manufacturer directly to a retailer.[17] A 2000 Consortium for Energy Efficiency (CEE) report determined that 5–10 percent of major appliance sales were made to commercial consumers such as builders, contractors, government sales, and property managers through distributors/wholesalers.[18]

3.7 REGULATORY PROGRAMS

The following section details current regulatory programs mandating energy conservation standards for residential clothes dryers and room air conditioners. Section 3.7.1 discusses current Federal energy conservation standards, while section 3.7.2 discusses the requirements of EISA 2007 and section 3.7.3 provides an overview of existing State standards. In addition, section

3.7.4 reviews standards in Canada that may impact the companies servicing the North American market.

3.7.1 Current Federal Energy Conservation Standards

Current Federal energy conservation standards exist for residential **clothes dryers**. NAECA amended EPCA to establish prescriptive standards for clothes dryers, requiring that gas dryers manufactured on or after January 1, 1988 not be equipped with a constant burning pilot and further requiring that DOE conduct two cycles of rulemakings to determine if more stringent standards are justified. (42 U.S.C. 6295 (g)(3) and (4)) On May 14, 1991, DOE published a final rule in the *Federal Register* (FR) establishing the first set of performance standards for residential clothes dryers (56 FR 22250); the new standards became effective on May 14, 1994. (10 CFR 430.32(h)) Table 3.7.1 presents these standards for residential clothes dryers, expressed as EF in terms of pounds (lb) of clothes washed per kilowatt-hour (kWh). DOE initiated a second standards rulemaking for residential clothes dryers by publishing an advance notice of proposed rulemaking (ANOPR) in the *Federal Register* on November 14, 1994 (hereafter "November 1994 ANOPR). 59 FR 56423. However, pursuant to the priority-setting process outlined in its *Procedures for Consideration of New or Revised Energy Conservation Standards for Consumer Products* (the "Process Rule") (61 FR 36974 (July 15, 1996); establishing 10 CFR part 430, subpart C, appendix A), DOE classified the standards rulemaking for residential clothes dryers as a low priority for its fiscal year 1998 priority-setting process. As a result, DOE suspended the standards rulemaking activities for them.

Table 3.7.1 Federal Energy Conservation Standards for Residential Clothes Dryers

Clothes Dryer Classification	Minimum EF *(lb/kWh))*
Electric, Standard (4.4 ft^3 or greater capacity)	3.01
Electric, Compact (120 V) (less than 4.4 ft^3 capacity)	3.13
Electric, Compact (240 V) (less than 4.4 ft^3 capacity)	2.90
Gas	2.67

NAECA established performance standards for **room air conditioners** that became effective on January 1, 1990, and directed DOE to conduct two cycles of rulemakings to determine if more stringent standards are justified. (42 U.S.C. 6295 (c)(1) and (2)) On March 4, 1994, DOE published in the *Federal Register* a NOPR for several products, including room air conditioners. 59 FR 10464. As a result of the Process Rule, DOE suspended activities to finalize standards for room air conditioners. DOE subsequently resumed rulemaking activities related to room air conditioners, and, on September 24, 1997, DOE published a final rule establishing an updated set of performance standards, with an effective date of October 1, 2000. (62 FR 50122; 10 CFR 40.32(b)). Table 3.7.2 presents these standards for room air conditioners in terms of energy efficiency ratio (EER), which is expressed as cooling capacity in Btu/h per watt (W) of input power.

Table 3.7.2 Federal Energy Conservation Standards for Room Air Conditioners

Room Air Conditioner Classification	Minimum EER *(Btu/h-W)*, effective as of Jan. 1, 1990	Oct. 1, 2000
1. Without reverse cycle, with LS, and less than 6,000 Btu/h	8.0	9.7
2. Without reverse cycle, with LS and 6,000 to 7,999 Btu/h	8.5	9.7
3. Without reverse cycle, with LS and 8,000 to 13,999 Btu/h	9.0	9.8
4. Without reverse cycle, with LS and 14,000 to 19,999 Btu/h	8.8	9.7
5. Without reverse cycle, with LS and 20,000 Btu/h or more	8.2	8.5
6. Without reverse cycle, without LS, and less than 6,000 Btu/h	8.0	9.0
7. Without reverse cycle, without LS and 6,000 to 7,999 Btu/h	8.5	9.0
8. Without reverse cycle, without LS and 8,000 to 13,999 Btu/h	8.5	8.5
9. Without reverse cycle, without LS and 14,000 to 19,999 Btu/h	8.5	8.5
10. Without reverse cycle, without LS and 20,000 Btu/h or more	8.2	8.5
11. With reverse cycle, with LS, and less than 20,000 Btu/h	8.5	9.0
12. With reverse cycle, without LS, and less than 14,000 Btu/h	8.0	8.5
13. With reverse cycle, with LS, and 20,000 Btu/h or more	8.5	8.5
14. With reverse cycle, without LS, and 14,000 Btu/h or more	8.0	8.0
15. Casement-Only	*	8.7
16. Casement-Slider	*	9.5

* Casement-only and casement-slider room air conditioners were not separate product classes under standards effective January 1, 1990. These units were subject to the applicable standards in classes 1 through 14 based on unit capacity and the presence or absence of louvered sides and a reverse cycle.

3.7.2 Energy Independence and Security Act of 2007

There is currently no prescriptive Federal energy conservation standard for standby power consumption for either residential clothes washers or room air conditioners, nor is standby power incorporated into the efficiency metric prescribed by the existing DOE test procedure for either product. On December 19, 2007, the President signed into law EISA 2007, which contains numerous amendments to EPCA. Section 310 of EISA 2007 amends Section 325 of EPCA to require any final rule establishing or revising a standard for a covered product, adopted after July 10, 2010, to incorporate standby mode and off mode energy use into a single amended or new standard. (42 U.S.C. 6295(gg)(3)(A)) If not feasible, the Secretary shall prescribe within the final rule a separate standard for standby mode and off mode energy consumption, if justified. (42 U.S.C. 6295(gg)(3)(B))

Off mode is defined by EISA 2007 as "the condition in which an energy-using product – (I) is connected to a main power source; and (II) is not providing any standby or active mode function." (42 U.S.C. 6295(gg)(1)(A)(ii)) Active mode refers to the one or more main functions, while standby is defined by EISA 2007 as "the condition in which an energy-using product (I) is connected to a main power source; and (II) offers 1 or more of the following user-oriented or protective functions: (aa) To facilitate the activation or deactivation of other functions (including active mode) by remote switch (including remote control), internal sensor, or timer. (bb) Continuous functions, including information or status displays (including clocks) or sensor-based functions." (*Id.*; 42 U.S.C. 6295(gg)(1)(A)(iii))

The final rule for this rulemaking was scheduled to be published in the Federal Register by June 30, 2011. Thus, according to EISA 2007, energy conservation standards for residential clothes dryers and room air conditioners that would be put forth from this rulemaking are required to incorporate standby mode and off mode energy consumption.

As noted above in section 0, the test procedure rulemaking to incorporate standby mode and off mode energy consumption in the energy descriptors for residential clothes dryers and room air conditioners was initiated in parallel with the current rulemaking. For both clothes dryers and room air conditioners, DOE has determined that it is technically feasible to incorporate standby mode and off mode energy consumption into overall energy consumption. Therefore, DOE adopted in the January 2011 TP Final Rule amendments which integrate standby mode and off mode energy use with the existing energy use metrics, creating new overall energy use descriptors, CEF and CEER for clothes dryers and room air conditioners, respectively. 76 FR 972, 991–992 (Jan. 6, 2011). Accordingly, DOE is adopting the amended energy conservation standards for residential clothes dryers and room air conditioners based on these integrated metrics.

3.7.3 State Energy Conservation Standards

For those States which currently regulate residential clothes dryers and/or room air conditioners, no State energy conservation standards differ from Federal standards.

3.7.4 Canadian Energy Conservation Standards

Canada's Energy Efficiency Regulations (hereafter Regulations) mandate minimum energy conservation standards for residential clothes dryers and room air conditioners.

Canadian Regulations stipulate minimum efficiency levels and definitions for electric residential **clothes dryers** which are identical to current U.S. Federal standards, mandating an EF of at least 3.01 for standard clothes dryers, an EF of at least 3.13 for compact (120 V) clothes dryers, and an EF of at least 2.90 for compact (240 V) clothes dryers. There are no Canadian Regulations covering gas clothes dryers.

For **room air conditioners**, Canada's Regulations are currently identical to U.S. Federal standards for all product classes. Canada's Regulations, however, provide a stipulation in the definition of covered products that limits cooling capacity to 36,000 Btu/h. U.S. Federal standards do not specify a maximum cooling capacity.

Canada has proposed increasing the required efficiency levels of room air conditioners, with an effective date of January 1, 2011. For many of the product classes, the proposed standards are the same as the current ENERGY STAR efficiency levels, which are roughly 10 percent higher than the minimum standard levels. The current and proposed efficiency levels are summarized in Table 3.7.3 below. The proposal also calls for measurement and reporting of standby and off mode energy use, anticipating future regulation of the energy use of these modes.

Table 3.7.3: Canada's Proposed Efficiency Requirements for Room Air Conditioners

Room Air Conditioner Classification	Minimum EER *(Btu/h-W)* Current Standard	Proposed
1. Without reverse cycle, with LS, and less than 6,000 Btu/h	9.7	10.7
2. Without reverse cycle, with LS and 6,000 to 7,999 Btu/h	9.7	10.7
3. Without reverse cycle, with LS and 8,000 to 13,999 Btu/h	9.8	10.8
4. Without reverse cycle, with LS and 14,000 to 19,999 Btu/h	9.7	10.7
5. Without reverse cycle, with LS and 20,000 Btu/h or more	8.5	9.4
6. Without reverse cycle, without LS, and less than 6,000 Btu/h	9.0	9.9
7. Without reverse cycle, without LS and 6,000 to 7,999 Btu/h	9.0	9.9
8. Without reverse cycle, without LS and 8,000 to 13,999 Btu/h	8.5	9.4
9. Without reverse cycle, without LS and 14,000 to 19,999 Btu/h	8.5	9.4
10. Without reverse cycle, without LS and 20,000 Btu/h or more	8.5	8.5
11. With reverse cycle, with LS, and less than 20,000 Btu/h	9.0	9.9
12. With reverse cycle, without LS, and less than 14,000 Btu/h	8.5	9.2
13. With reverse cycle, with LS, and 20,000 Btu/h or more	8.5	9.5
14. With reverse cycle, without LS, and 14,000 Btu/h or more	8.0	8.8
15. Casement-Only	8.7	9.5
16. Casement-Slider	9.5	9.5

3.7.5 International Standby Power Regulatory Programs

The International Energy Agency (IEA) has raised awareness of standby power through publications, international conferences, and policy advice to governments. In 1999, the IEA developed the "1-Watt Plan," which proposed reducing standby power internationally in electronic devices and which advocates that all countries harmonize energy policies and adopt the same definition and test procedure. The IEA has advocated a 1 W requirement for all consumer electrical products (unless specifically excluded) in standby mode. The IEA also stated that IEC Standard 62301 provides an internationally sanctioned definition and test procedure for standby power which is now widely specified and used.[j]

Australia has announced plans to implement a mandatory horizontal 1 W requirement for all consumer electrical products by 2012, including room air conditioners and clothes dryers.[19]

The European Union (EU) enacted the Commission Regulation (EC) No. 1275/2008 of December 17, 2008, implementing design requirements for standby and off mode power for electrical and electronic household and office equipment, including clothes dryers. Annex II of the regulation specifies the following maximum power requirements:

1. One year after this Regulation has come into force:

[j] For more information visit http://www.iea.org/.

(a) Power consumption in ‘off mode’:

Power consumption of equipment in any off-mode condition shall not exceed [1.00] W.

(b) Power consumption in ‘standby mode(s)’:

The power consumption of equipment in any condition providing only a reactivation function, or providing only a reactivation function and a mere indication of enabled reactivation function, shall not exceed [1.00] W.

The power consumption of equipment in any condition providing only information or status display, or providing only a combination of reactivation function and information or status display, shall not exceed [2.00] W.

(c) Availability of off mode and/or standby mode

Equipment shall, except where this is inappropriate for the intended use, provide off mode and/or standby mode and/or another condition which does not exceed the applicable power consumption requirements for off mode and/or standby mode when the equipment is connected to the mains power source.

2. Four years after this Regulation has come into force:

(a) Power consumption in ‘off mode’:

Power consumption of equipment in any off-mode condition shall not exceed [0.50] W.

(b) Power consumption in ‘standby mode(s)’:

The power consumption of equipment in any condition providing only a reactivation function, or providing only a reactivation function and a mere indication of enabled reactivation function, shall not exceed [0.50] W.

The power consumption of equipment in any condition providing only information or status display, or providing only a combination of reactivation function and information or status display, shall not exceed [1.00] W.

(c) Availability of off mode and/or standby mode

Equipment shall, except where this is inappropriate for the intended use, provide off mode and/or standby mode and/or another condition which does not exceed the applicable power consumption requirements for off mode and/or standby mode when the equipment is connected to the mains power source.

(d) Power management

When equipment is not providing the main function, or when other energy-using product(s) are not dependent on its functions, equipment shall, unless inappropriate for the intended use, offer a power management function, or a similar function, that switches equipment after the shortest possible period of time appropriate for the intended use of the equipment, automatically into:

— standby mode, or

— off mode, or

— another condition which does not exceed the applicable power consumption requirements for off mode and/or standby mode when the equipment is connected to the mains power source. The power management function shall be activated before delivery.

3.8 VOLUNTARY PROGRAMS

DOE reviewed several voluntary programs promoting energy-efficient residential appliances in the United States. Many programs, including the CEE, ENERGY STAR, and the Federal Energy Management Program (FEMP), establish voluntary energy conservation standards for these products.

3.8.1 Consortium for Energy Efficiency

The CEE[k] develops initiatives for its North American members to promote the manufacture and purchase of energy efficient products and services. The goal of the organization is to induce lasting structural and behavioral changes in the marketplace, resulting in the increased adoption of energy-efficient technologies.

CEE issues voluntary specifications for **room air conditioners**. Qualifying units must use at least 15 percent less electricity, based on EER, than the Federal standard. Table 3.8.1 presents the room air conditioner efficiency specifications, effective January 2003, under its Super-Efficient Home Appliance Initiative (SEHA). Unlike for Federal standards, no distinction is made among the features present on a qualifying unit (*i.e.,* louvered sides, reverse cycle, etc.). The classes are differentiated only by cooling capacity.

[k] For more information, please visit *www.cee1.org*.

Table 3.8.1 CEE Criteria for Room Air Conditioners

Product Class *(Btu/h)*	**Tier 1 (EER,** *Btu/h-W***)**	**Tier 2 (EER,** *Btu/h-W***)**
< 8,000	11.2	11.6
8,000 to 13,999	11.3	11.8
14,000 to 19,999	11.2	11.6
≥ 20,000	9.8	10.2

3.8.2 ENERGY STAR

ENERGY STAR, a voluntary labeling program jointly administered by the U.S. Environmental Protection Agency (EPA) and DOE, identifies energy efficient products through a qualification process[1]. To qualify, a product must exceed Federal minimum standards by a specified amount, or if no Federal standard exists, exhibit selected energy-saving features. The ENERGY STAR program works to recognize the top quartile of products on the market, meaning that approximately 25 percent of the models on the market at the time the qualifying criteria are specified meet or exceed the ENERGY STAR levels. ENERGY STAR specifications exist for several products, including room air conditioners.

Prior to November, 2005, ENERGY STAR **room air conditioner** criteria existed for only cooling-only units; *i.e.*, those without a reverse cycle or electric resistance heating. New criteria which became effective November 16, 2005 added ENERGY STAR specifications for room air conditioners with reverse cycle operation. The current ENERGY STAR criteria for room air conditioners are listed in Table 3.8.2. According to the ENERGY STAR program, 54 percent of room air conditioners sold in 2006 were ENERGY STAR-qualified.

[1] For more information, please visit *www.energystar.gov*.

Table 3.8.2 ENERGY STAR Criteria for Room Air Conditioners

Without reverse cycle and with louvered sides	**Required EER** *(Btu/h-W)*
1. Less than 6,000 Btu/h	≥ 10.7
2. 6,000 to 7,999 Btu/h	≥ 10.7
3. 8,000 to 13,999 Btu/h	≥ 10.8
4. 14,000 to 19,999 Btu/h	≥ 10.7
5. 20,000 Btu/h or more	≥ 9.4
Without reverse cycle and without louvered sides	
6. Less than 6,000 Btu/h	≥ 9.9
7. 6,000 to 7,999 Btu/h	≥ 9.9
8. 8,000 to 13,999 Btu/h	≥ 9.4
9. 14,000 to 19,999 Btu/h	≥ 9.4
10. 20,000 Btu/h or more	≥ 9.4
With reverse cycle and with louvered sides	
11. Less than 20,000 Btu/h	≥ 9.9
12. 20,000 Btu/h or more	≥ 9.4
With reverse cycle and without louvered sides	
13. Less than 14,000 Btu/h	≥ 9.4
14. 14,000 Btu/h or more	≥ 8.8
Casement	
15. Casement-Only	≥ 9.6
16. Casement-Slider	≥ 10.5

3.8.3 Federal Energy Management Program

DOE's Federal Energy Management Program[m] (FEMP) works to reduce the cost and environmental impact of the Federal government by advancing energy efficiency and water conservation, promoting the use of distributed and renewable energy, and improving utility management decisions at Federal sites. FEMP helps Federal buyers identify and purchase energy efficient equipment, including certain residential appliances.

FEMP issues energy efficiency recommendations for **room air conditioners**. Table 3.8.3 presents the room air conditioner recommendations.

[m] For more information, please visit www.eere.energy.gov/femp.

Table 3.8.3 FEMP Recommendations for Room Air Conditioners

Air Conditioner Type and Capacity	**Required EER** *(Btu/h-W)*
With louvered sides, < 20,000 Btu/h	≥ 10.7
With louvered sides, ≥ 20,000 Btu/h	≥ 9.4
Without louvered sides, < 8,000 Btu/h	≥ 9.9*
Without louvered sides, ≥ 8,000 Btu/h	≥ 9.4
* FEMP states that currently there are no models that can meet this recommendation, and suggests purchasing a unit with the best available EER.	

FEMP estimates that a typical household using a louvered-side model room air conditioner with a cooling capacity of 10,000 Btu/h and 750 operating hours per year with an EER of 9.8 (DOE minimum standard) can save $40 in energy costs over the lifetime of the unit (assuming Federal average energy prices) by upgrading to a unit with an EER of 10.7 (FEMP recommendation). The lifetime energy savings increase to $80 by purchasing a unit with an EER of 11.5.

Executive Order 13221 Energy Efficient Standby Power Devices, signed July 31, 2001, requires that Federal agencies purchase commercially available products with low standby power. In addition, Executive Order 13221 of July 31, 2001, directs Federal agencies, when purchasing a product that contains an internal standby power function or that uses an external standby power device, to purchase such a product that consumes no more than 1 W in standby power mode or, if such a product is not available, to select a product with the lowest available standby power consumption. These requirements shall apply only if the lower-wattage eligible product is lifecycle cost effective and practicable, and the utility and performance of the product is not compromised by the lower wattage requirement. 66 FR 40571.

3.8.4 Rebates for Highly Energy-Efficient Products

Electric utilities and other organizations promote the purchase of highly energy efficient residential clothes washers through consumer rebates. Typically, these programs offer rebates for products meeting existing ENERGY STAR efficiency levels. Table 3.8.4 lists some rebates that were offered in 2008. Some utilities also offer incentives to retire old and inefficient appliances.

Table 3.8.4 Rebates Offered for Highly Energy Efficient Room Air Conditioners in 2008[20]

Utility/Organization*	**Rebate Level** *($)*
Alliant Energy (Iowa and Minnesota)	50 (ENERGY STAR)
Efficiency Vermont	25 (ENERGY STAR) 40 (CEE Tier 1)
Los Angeles Department of Water and Power (CA)	50 (ENERGY STAR)
Pacific Gas and Electric Company (Northern California)	50 (ENERGY STAR)
Sacramento Municipal Utility District (CA)	50 (ENERGY STAR)
San Diego Gas & Electric (CA)	50 (ENERGY STAR)

* The table includes a survey of a limited number of rebate programs. Additional programs may exist.

3.9 HISTORICAL SHIPMENTS

Awareness of annual product shipment trends is an important aspect of the market assessment and in the development of the standards rulemaking. DOE reviewed data collected by the U.S. Census Bureau, EPA, and AHAM to evaluate residential appliance product shipment trends and the value of these shipments. Knowledge of such trends will be used during the shipments analysis (chapter 9 of this TSD).

3.9.1 New Home Starts

Trends in new home starts may directly affect shipments of certain home appliances. While there is certainly both a replacement and remodeling market for some appliances including residential clothes dryers, these products are also fixtures in many new homes. Room air conditioner shipments are not as greatly impacted by new home starts, as they are often purchased for use in existing construction.

Figure 3.9.1 presents the number of new single-family and multi-family housing units started in the United States from 1998–2009. Over the 5-year period from 2000–2005, single-family home starts increased 39.4 percent, to 1,716,000 units annually. However, between 2005 and 2009, single-family home starts decreased 74.1 percent, to 445,100 units annually. Multi-family unit starts remained relatively flat between 1998 and 2005, hovering around 350,000 units annually. However, between 2005 and 2009, multi-family unit starts decreased by 69.1 percent, to around 108,900 units annually.[21]

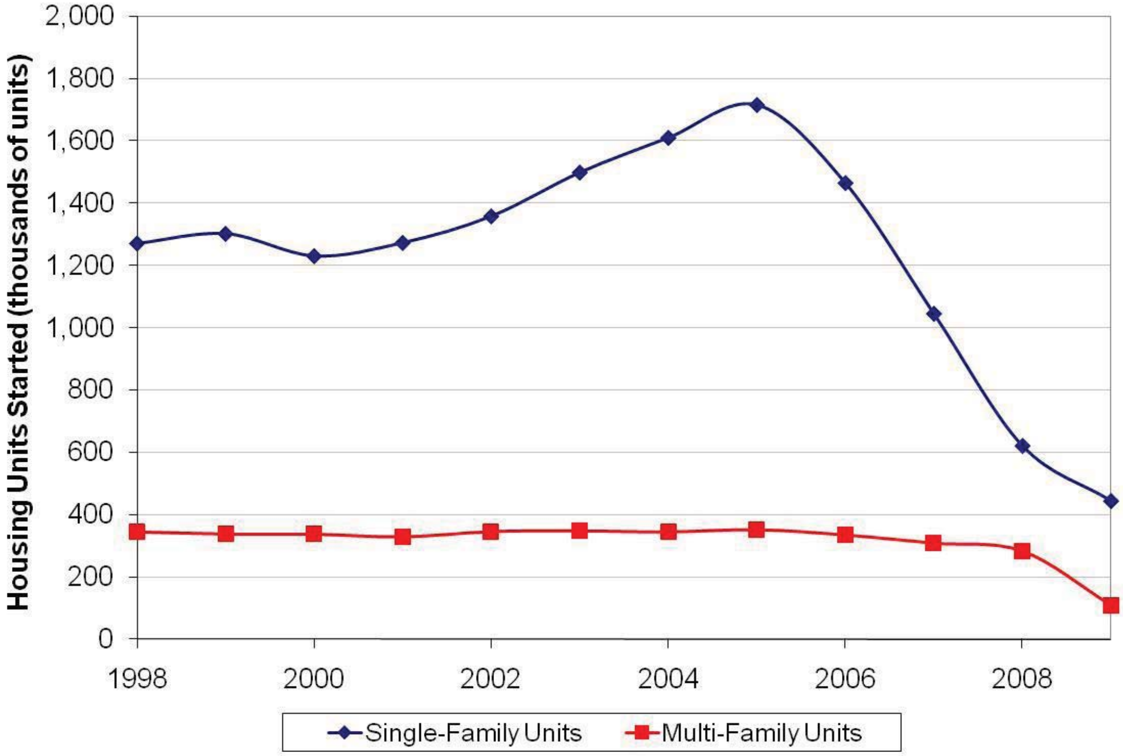


Figure 3.9.1 New Privately Owned Single-Family and Multi-Family Housing Unit Starts in the United States from 1998–2009 [22]

3.9.2 Unit Shipments

AHAM submitted data for the annual unit shipments for residential **clothes dryers**, and DOE obtained additional shipments data from *Appliance Magazine*. Table 3.9.1 presents the annual shipments of clothes dryers for the 15-year period from 1993 to 2008. The shipments of electric clothes dryers increased 73 percent from 1993 to 2006, to about 6.4 million units in 2006. However, between 2006 and 2008, shipments of electric clothes dryers decreased by 11.6 percent, to 5.6 million units in 2008. The shipments of gas dryers increased 40 percent from 1993 to 2006, to about 1.6 million units in 2006. Again, between 2006 and 2008, shipments of gas clothes dryers decreased by about 16 percent, to about 1.4 million in 2008.

Table 3.9.1 Industry Shipments of Residential Clothes Dryers (Domestic and Import, in Thousands of Units)[23]

Year	Clothes Dryers *(Thousands)*				
	Electric	Standard Electric	Compact Electric	Gas	Total
2008**	5,620			1,353	6,973
2007**	6,035			1,530	7,565
2006	6,360	6,246	114	1,614	7,974
2005	6,408	6,330	78	1,707	8,115
2004	6,262	6,159	103	1,660	7,922
2003	5,718	5,622	96	1,616	7,334
2002	5,402			1,490	6,892
2001	5,117			1,384	6,501
2000	5,095			1,480	6,575
1999	4,865			1,444	6,309
1998	4,482			1,307	5,789
1997	4,115			1,195	5,310
1996	3,947			1,193	5,140
1995	3,823			1,169	4,992
1994	3,838			1,239	5,077
1993	3,674			1,156	4,830

*AHAM did not provide data for standard and compact electric clothes dryers prior to 2003, nor any clothes dryer shipments data for 2007 and 2008.
**Source: September 2008 and 2009 *Appliance Magazine* "Share-of-Market Picture".

AHAM's *Fact Book* 2003 and 2005, as well as *Appliance Magazine*, provide annual unit shipments for room air conditioners. Table 3.9.2 presents the annual shipments of **room air conditioners** for the 14-year period from 1994 to 2008. Shipments of room air conditioners increased sharply in 1999 and again in 2003 and 2006.

Table 3.9.2 Industry Shipments of Room Air Conditioners (Domestic and Import, in Thousands of Units) [24]

Year	Room Air Conditioners *(Thousands)*
2008*	9,086
2007*	9,550
2006*	10,055
2005	8,032
2004	8,082
2003	8,216
2002	6,153
2001	5,575
2000	6,496
1999	6,114
1998	4,403
1997	4,123
1996	4,825
1995	4,300
1994	3,853

*Shipments data for 2006 through 2008 were obtained from the September 2007-2009 *Appliance Magazine* "Share-of-Market Picture".

ENERGY STAR market share data are an indicator of the demand for energy efficient products. Table 3.9.3 shows the ENERGY STAR-qualified **room air conditioner** shipments and market share from 1997 to 2006 provided in the ENERGY STAR *Room Air Conditioner 2007 Product Snapshot*. Sales of ENERGY STAR qualified room air conditioners have grown faster than the overall total sales of clothes washers over the 10-year period, with market share increasing more than 40 percent.

Table 3.9.3 ENERGY STAR Shipments for Room Air Conditioners (Domestic and Import)

Year	Shipments			% ENERGY STAR of Total[25]
	ENERGY STAR-Qualified	Other	Total[26]	
2006	5,429,862	4,625,438	10,055,300*	54
2005	4,176,640	3,855,360	8,032,000	52
2004	2,828,700	5,253,300	8,082,000	35
2003	2,382,640	5,833,360	8,216,000	29
2002	2,215,080	3,937,920	6,153,000	36
2001	669,000	4,906,000	5,575,000	12
2000	1,234,240	5,261,760	6,496,000	19
1999	794,820	5,319,180	6,114,000	13
1998	572,390	3,830,610	4,403,000	13
1997	494,760	3,628,240	4,123,000	12

*Total shipments data for 2006 from the September 2007 *Appliance Magazine* "Share-of-Market Picture for 2006".

3.9.3 Value of Shipments

Table 3.9.4 provides the value of household laundry equipment shipments, which includes residential **clothes dryer** and clothes washer shipments, from 1994 to 2008 based upon data from the U.S. Census Bureau's *Annual Survey of Manufacturers* (ASM)[n]. The ASM expresses all dollar values in nominal dollars; *i.e.*, 2008 data are expressed in 2008 dollars, and 2005 data are expressed in 2005 dollars. Using the Gross Domestic Product Implicit Price Deflator, DOE converted each year's value of shipments to 2008 dollars. In constant dollars, the value of household laundry shipments increased 14 percent from 1994 to 2005, but then decreased 25 percent between 2005 and 2008. During the same period, unit shipments of residential clothes dryers increased about 37 percent, suggesting that the U.S. laundry appliance industry is very competitive.

[n] Available online at *www.census.gov/manufacturing/asm/index.html*.

Table 3.9.4 Household Laundry Equipment Value of Shipments by Year[27]

Year	Value of Shipments in Nominal Dollars *($ million)*	Value of Shipments in 2008 Dollars *($ million)*
2008	4,232	4,232
2007	4,678	4,780
2006	5,129	5,395
2005	5,222	5,672
2004	4,987	5,598
2003	4,658	5,377
2002	4,352	5,132
2001	4,549	5,451
2000	4,420	5,416
1999	4,365	5,464
1998	4,249	5,397
1997	3,710	4,766
1996	3,699	4,836
1995	3,541	4,717
1994	3,671	4,992

Table 3.9.5 provides the value of shipments for the NAICS product class which includes **room air conditioners** and dehumidifiers, other than portable dehumidifiers (NAICS product class code 3334156). The value of shipments for these products has decreased 72 percent from 1994 to 2008 while unit shipments of room air conditioners have increased about 136 percent during the same time period, indicating significant industry competition.

Table 3.9.5 "Room Air-Conditioners and Dehumidifiers, Except Portable Dehumidifiers" Product Class Value of Shipments by Year[28]

Year	Value of Shipments in Nominal Dollars *($ million)*	Value of Shipments in 2008 Dollars *($ million)*
2008	452	452
2007	646	660
2006	542	570
2005	572	621
2004	598	671
2003	820	947
2002	839	989
2001	944	1,131
2000	984	1,206
1999	1,177	1,473
1998	1,034	1,313
1997	979	1,258
1996	1,367	1,787
1995	1,300	1,732
1994	1,183	1,609

According to data presented in the AHAM 2003 *Fact Book*, many old appliances are still being used after consumers purchase new units of same product. Table 3.9.6 presents the various methods by which consumers dispose of their older appliances.

Table 3.9.6 Disposition of Previous Appliance (Percentage)[29]

Product	**Kept It** *(%)*	**Left with Previous Home** *(%)*	**Sold / Gave Away** *(%)*	**Recycling Facility** *(%)*	**Left at Curb for Disposal** *(%)*	**Retailer Took Away** *(%)*
Clothes Dryers	5	19	25	18	10	23
Room Air Conditioners	16	21	40	9	9	4

3.9.4 Imports and Exports

There is a large market for the import and export of home appliances. Each month AHAM publishes import and export data for certain home appliances. This data is released by the U.S. Census Bureau and aggregated by a third party. On the whole, major appliance unit imports decreased 9.7 percent in 2009 as compared to 2008. Major appliance unit exports decreased 17.5 percent over the same period.

Table 3.9.7 shows selected import data from AHAM's *Import/Export Trade Report – December 2009*.[30] For non-coin-operated clothes dryers with a capacity less than 10 kilograms (kg) (*i.e*., residential clothes dryers), the number of units imported decreased by 19.4 percent from 2008 to 2009, while the value of units imported decreased by 13.7 percent over that same period. For room air conditioners with a capacity less than 2.93 kW (10,000 Btu/h), both the number and value of units imported decreased by more than 18 percent from 2008 to 2009. For room air conditioners with a capacity between 2.93 to 4.98 kW (10,000 to 17,000 Btu/h) both the number and value of units imported decreased by more than 7.5 percent. For room air conditioners with a capacity greater than 4.98 kW (17,000 Btu/h) both the number and value of units imported decreased by more than 27 percent

Table 3.9.7 2008-2009 Imports of Appliances Covered by this Rulemaking[31]

Appliance Description	Jan. – Dec. 2009	Jan. – Dec. 2008	% Change	Jan. – Dec. 2009	Jan. – Dec. 2008	% Change
	Units			*$ Mil (Nominal)*		
Drying machines, except coin-operated, capacity ≤ 10 kg	935,249	1,159,852	-19.4	209.598	242.892	-13.7
Air conditioners, window/wall, capacity < 2.93 kW (<10,000 Btu/h)	3,869,851	4,965,619	-22.1	424.696	519.801	-18.3
Air conditioners, window/wall, self-contained, capacity 2.93-4.98 kW (10,000 to 17,000 Btu/h)	1,751,125	2,109,678	-17.0	349.816	378.262	-7.5
Air conditioners, window/wall, self-contained, capacity ≥4.98 kW (≥17,000 Btu/h)	432,145	636,289	-32.1	130.253	178.319	-27.0

Table 3.9.8 shows selected export data from AHAM's *Import/Export Trade Report – December 2009*.[32] For the 1-year period from 2008 to 2009, the number and value of unit exports of non-coin-operated clothes dryers and all room air conditioners decreased significantly.

Table 3.9.8 2007-2008 Exports of Appliances Covered by this Rulemaking[33]

Appliance Description	Jan. – Dec. 2009	Jan. – Dec. 2008	% Change	Jan. – Dec. 2009	Jan. – Dec. 2008	% Change
	Units			*$ Mil (Nominal)*		
Drying machines, except coin-operated, capacity ≤ 10 kg	129,186	158,492	-18.5	27.817	34.725	-19.9
Air conditioners, window/wall, capacity < 2.93 kW/h (<10,000 Btu/h)	72,358	103,999	-30.4	23.662	33.536	-29.4
Air conditioners, window/wall, self-contained, capacity 2.93-4.98 kW/h (10,000 to 17,000 Btu/h)	48,483	73,737	-34.2	21.270	30.555	-30.4
Air conditioners, window/wall, self-contained, capacity ≥4.98 kW/h (≥17,000 Btu/h)	39,453	51.673	-23.6	26.915	36.386	-26.0

3.10 HISTORICAL EFFICIENCIES

Table 3.10.1 shows the historical efficiency trends and the percentage of domestic shipments by EER classification for **room air conditioners** from 1980 to 2004, as provided in the AHAM *Fact Book* 2005. New coil designs, increased motor and compressor efficiencies, and better air circulation systems have all contributed to the 11-percent efficiency increase from 1990 through 2004. The percentage of domestic shipments by EER classification also shows a trend towards high efficiency room air conditioners. The increases in EER and percent of shipments of higher efficiency room air conditioners in 2000 and 2001 were a result of the new energy conservation standards which became effective in October 1, 2000.

Table 3.10.1 Room Air Conditioner Energy Efficiency and Consumption Trends (Shipment Weighted Averages)[34]

Year	EER *(Btu/h)*	Percentage of Domestic Shipments *(%)* Less than 8.5 EER	8.5 - 9.4 EER	9.5 EER and Higher
2004	9.71	0.04	11.2	88.8
2003	9.75	0.03	9.0	91.0
2002	9.75	0.02	12.4	87.6
2001	9.63	0.1	13.8	86.0
2000	9.3	14.2	34.2	51.5
1999	9.07	26.9	41.4	31.7
1998				
1997	9.09	16.7	47.3	36.0
1996	9.08	16.0	49.3	34.7
1995	9.03	19.3	51.9	28.8
1994	8.97	24.1	50.9	25.0
1993	9.05	24.8	55.3	19.9
1992	8.88	24.6	58.1	17.3
1991	8.8	27.5	57.2	15.3
1990	8.73	28.9	58.3	12.8
1980	7.02	88.6	9.3	2.1

3.11 MARKET SATURATION

AHAM's *Fact Book* 2005 presents the market saturation for residential clothes dryers and room air conditioners. Table 3.11.1 presents the appliance saturation and percentage of U.S. households with each product as reported in the AHAM *Fact Book* 2005. The number of U.S. households with each product is based on U.S. Census Bureau projections of occupied units in the relevant year. The saturation of gas dryers as a percentage of households has remained constant since 2001, while the saturation of electric dryers has increased. Conversely, the saturation of room air conditioners as a percentage of households has decreased somewhat since 1990.

Table 3.11.1 Appliance Saturation (Number in Millions and Percentage of U.S. Households with Product)[35]

	1970		1982		1990		2001		2005	
Product	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**
Dryers, Electric	18.6	29.3	42.3	50.6	56.1	60.1	61.8	59.3	67.6	62.1
Dryers, Gas	7.8	12.3	12.3	14.7	19.1	20.5	19.8	19	20.7	19
Room Air Conditioners	16.9	25	22.6	27	30.2	32.4	26.9	25.8	27.4	25.2

3.12 PRODUCT RETAIL PRICES

Table 3.12.1 presents the average retail prices of residential clothes dryers and room air conditioners for select years between 1980 and 2002. The retail prices presented in nominal dollars are obtained from the AHAM *Fact Book* 2003. To adjust these prices to constant 2002 dollars, the values are scaled by the annual U.S. city average Consumer Price Index (CPI), published by the U.S. Department of Labor's Bureau of Labor Statistics (BLS). Although retail prices in nominal dollars for electric and gas **clothes dryers** have increased since 1980, the increase has been at a slower rate than the CPI, so that in constant 2002 dollars the retail prices have decreased. Prices of **room air conditioners** in both nominal and 2002 dollars have decreased in the same time period.

Table 3.12.1 Residential Appliance Retail Prices[36]

Product	Average Retail Prices *(Nominal $)*			Average Retail Prices *(2002$)*		
	1980	**1994**	**2002**	**1980**	**1994**	**2002**
Electric Clothes Dryers	286	327	396	624	397	396
Gas Clothes Dryers	315	325	467	688	395	467
Room Air Conditioners	372	351	322	812	426	322

DOE used the consolidated room air conditioner database developed for the energy efficiency analysis in section 3.15.3.2 to produce a more recent overview of the retail prices. The prices shown represent retail prices offered by a wide variety of retailers and internet distributors. The prices reflected information collected in August 2008.

Figure 3.12.1 and Figure 3.12.2 show the retail price versus cooling capacity of each **room air conditioner** listed in the databases, shown separately for product class groups 1-5 and 6-10. There is a definite positive trend in cost for both of the graphs, however, the range of prices at a given capacity is much wider for product classes 1 through 5. The second graph shows that there are a limited number of products in the product class 6 through 10 group with capacities higher than 15,000 Btu/h. This represents primarily product classes 9 and 10.

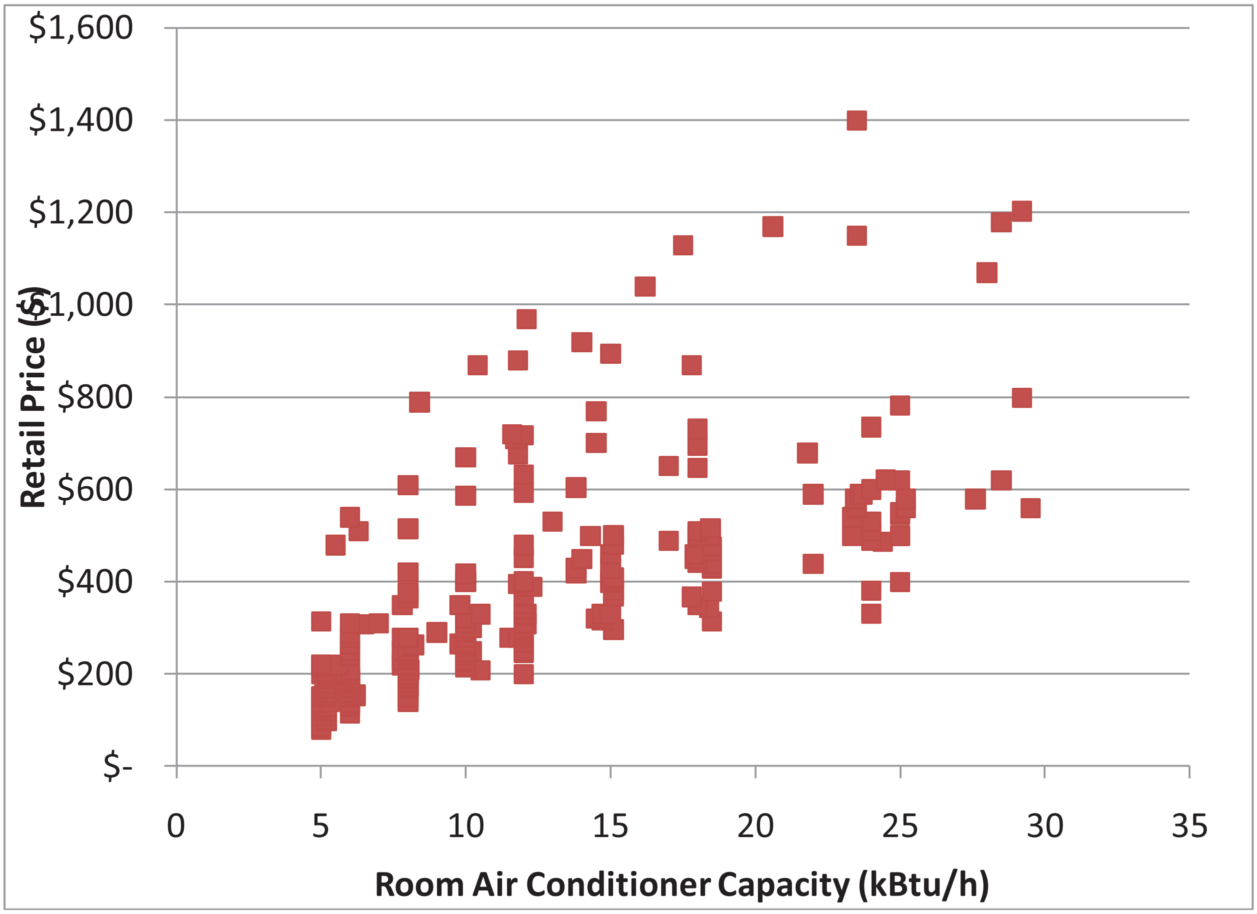


Figure 3.12.1 Retail Prices for Room Air Conditioners, Product Classes 1 through 5

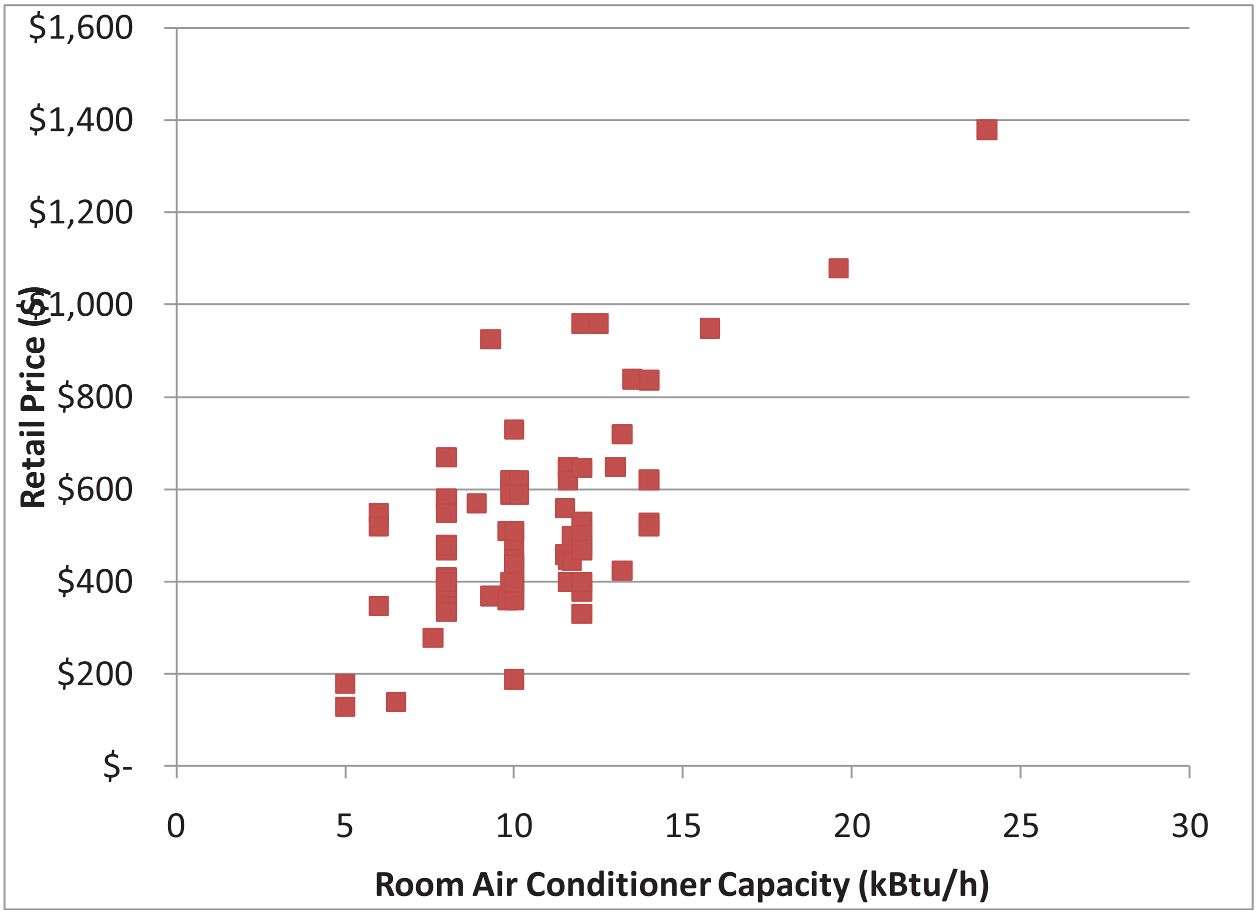


Figure 3.12.2 Retail Prices for Room Air Conditioners, Product Classes 6 through 10

Figure 3.12.3 through Figure 3.12.8 show the retail price as a function of EER for the room air conditioners in the consolidated database, specifically for the product classes analyzed in detail in the engineering analysis (product classes 1, 3, 5, and 8). The figures show concentrations of products at the baseline and ENERGY STAR efficiency levels. Figure 3.12.3 shows an approximate $50 price increment for those units in product class 1 with an ENERGY STAR rating. However, there are not strong trends of price as a function of EER observed for product classes 3, 5, and 8.

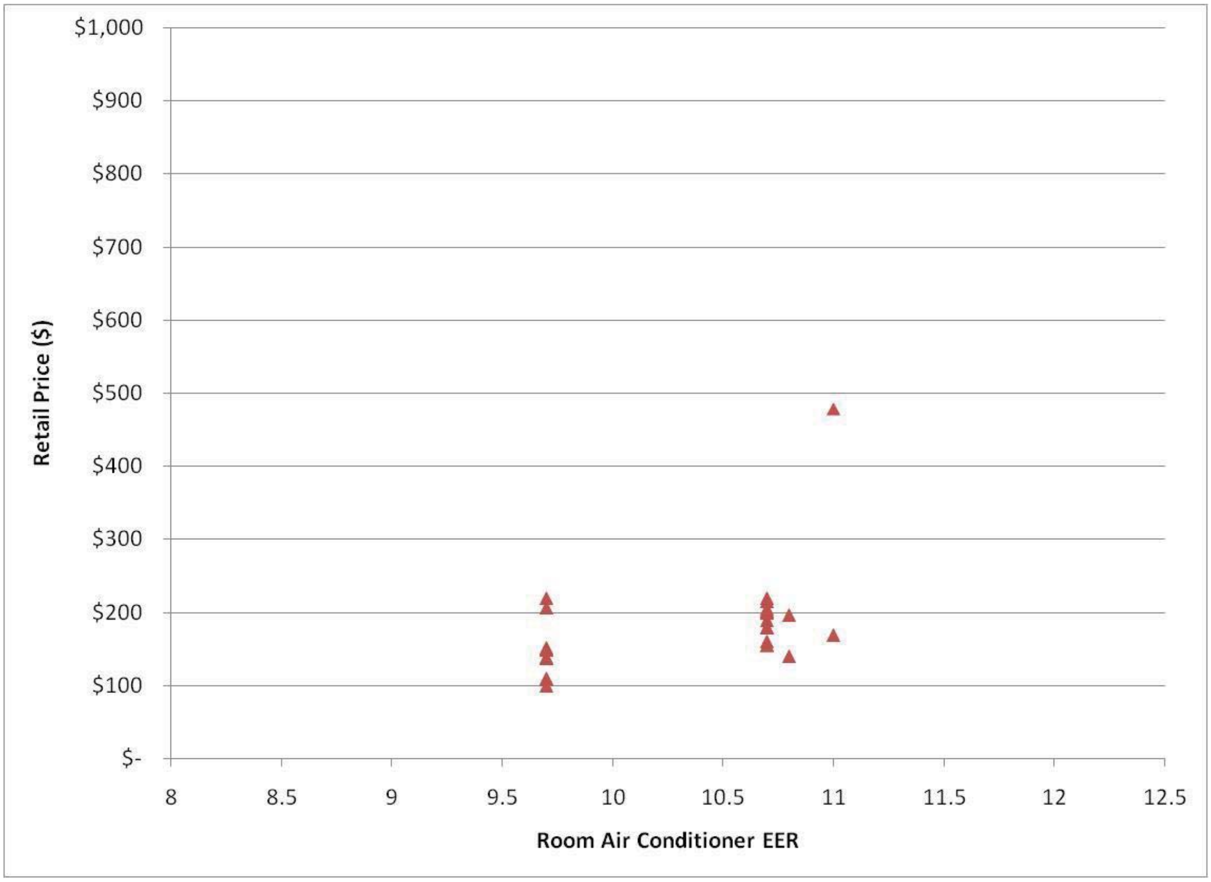


Figure 3.12.3 Retail Price versus EER for Product Class 1

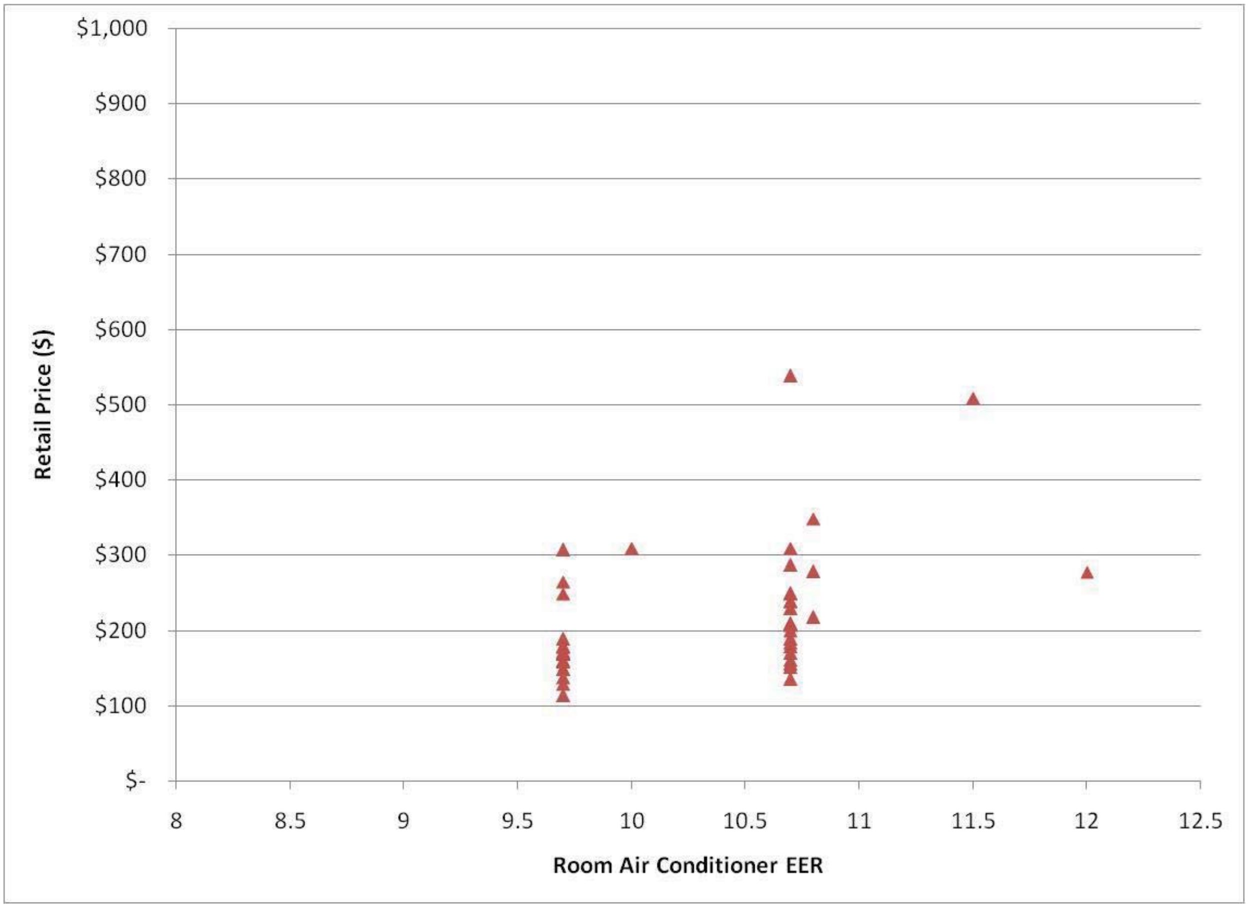


Figure 3.12.4 Retail Price versus EER for Product Class 2

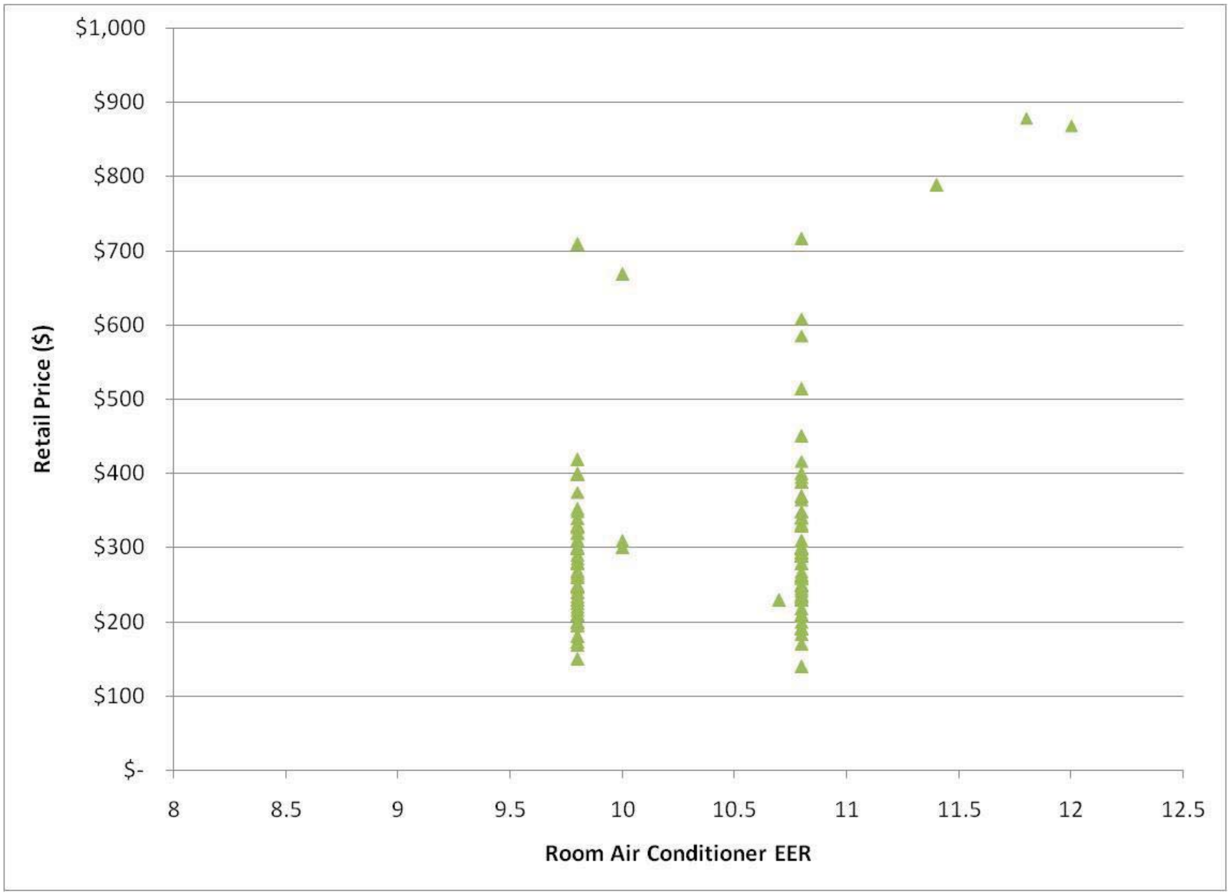


Figure 3.12.5 Retail Price versus EER for Product Class 3

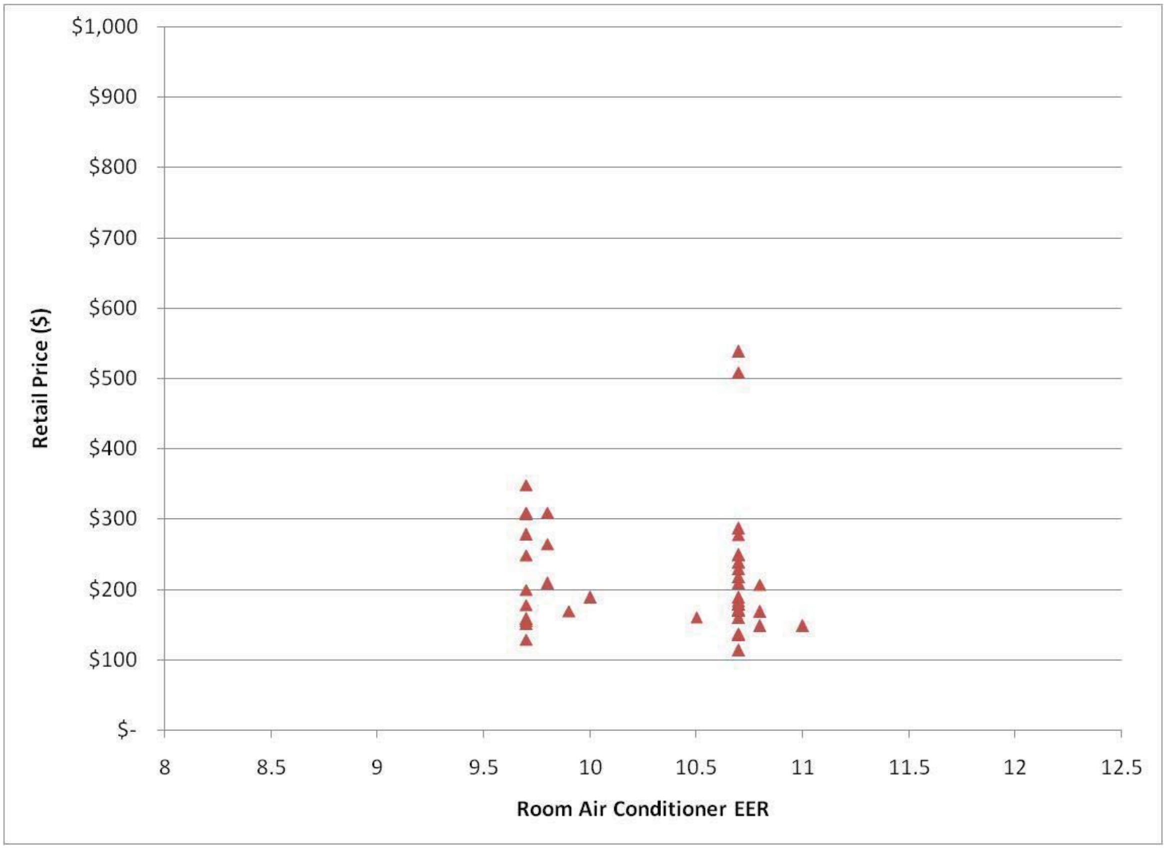


Figure 3.12.6 Retail Price versus EER for Product Class 4

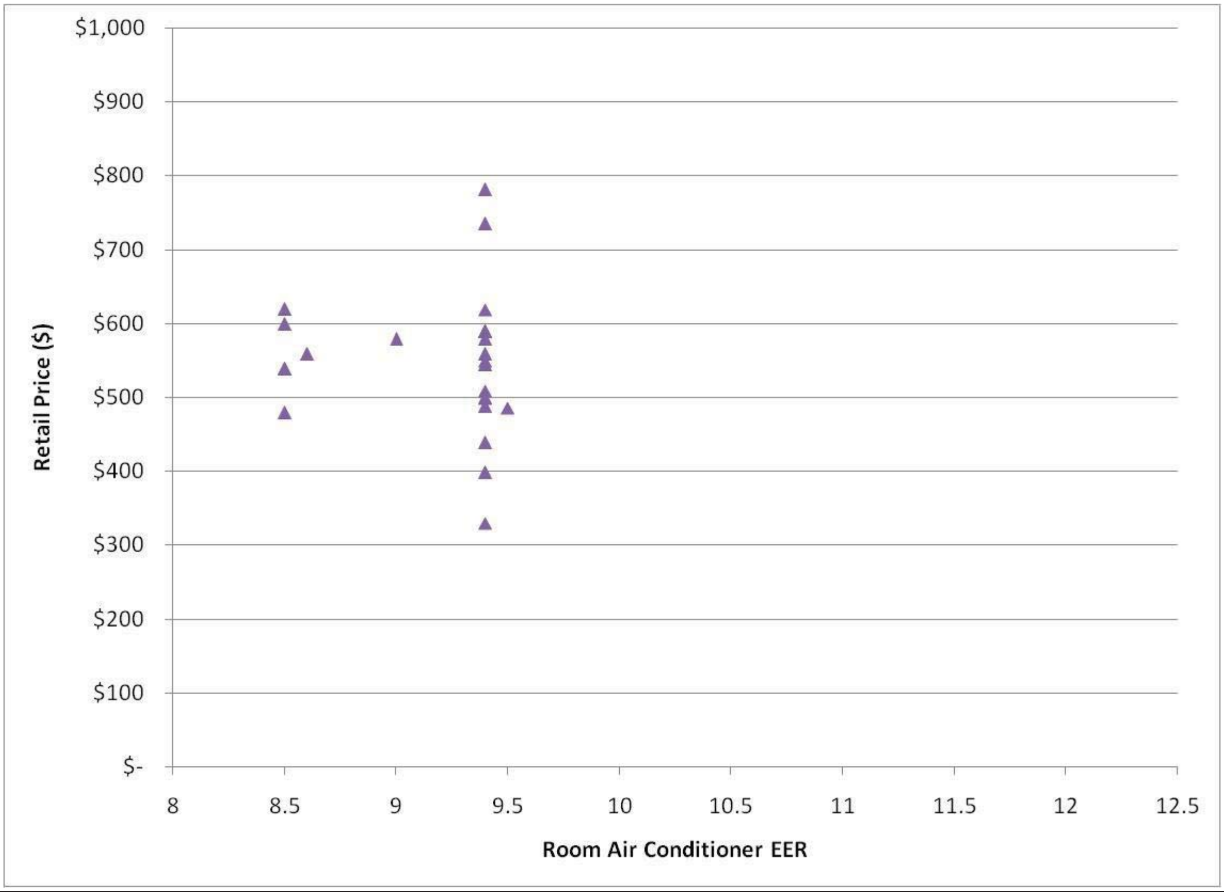


Figure 3.12.7 Retail Price versus EER for Product Class 5

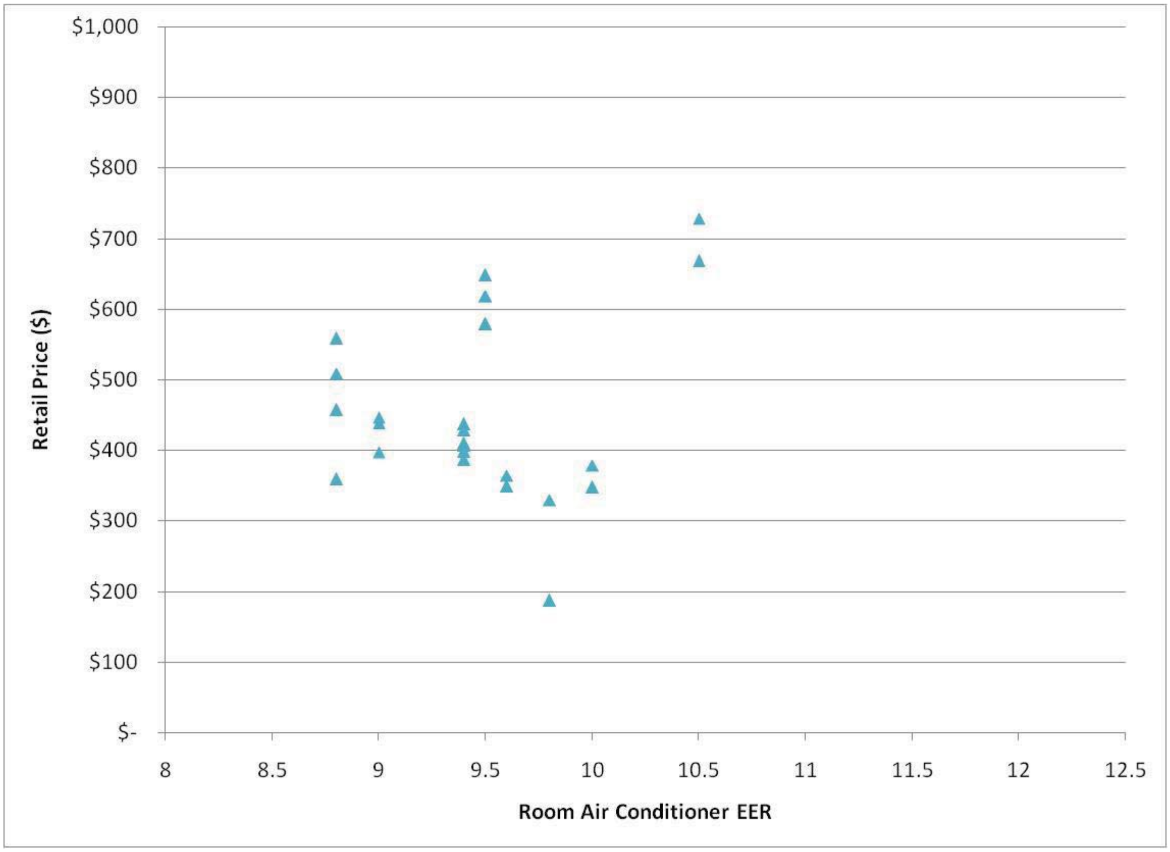


Figure 3.12.8 Retail Price versus EER for Product Class 8

3.13 INDUSTRY COST STRUCTURE

DOE developed the household appliance, household laundry, and air-conditioning and warm air heating and commercial/industrial refrigeration equipment industries cost structures from publicly available information from the ASM (Table 3.13.1 through Table 3.13.6) and from the Securities and Exchange Commission (SEC) 10-K reports filed by publicly owned manufacturers (summarized in Table 3.13.7). Table 3.13.1 presents the home appliance industry employment levels and earnings from 1994–2008. The statistics illustrate a steady decline in the number of production and non-production workers in the industry.

Because the ASM expresses all dollar values in constant 2008 dollars, the following table shows that as industry employment levels decline, the industry payroll is also decreasing. The percent decrease in total industry employees tracks closely with the percent decrease in payroll for all employees.

Table 3.13.1 Household Appliance Industry Employment and Earnings [37]

Year	Production Workers (‘000)	All Employees (‘000)	Payroll for All Employees (2008$ Mil)
2008	49.1	57.5	2,296.0
2007	56.2	65.5	2,537.9
2006	60.0	69.7	2,777.8
2005	64.3	76.9	2,928.2
2004	69.4	83.7	3,244.1
2003	71.0	85.3	3,326.1
2002	73.5	88.8	3,525.2
2001	76.6	92.6	3.693.5
2000	82.7	99.5	4,023.4
1999	82.3	97.9	3,892.2
1998	82.4	99.5	3,919.5
1997	79.8	97.2	3,742.3
1996	87.1	108.1	4,010.7
1995	88.9	110.8	4,077.0
1994	90.4	110.4	4,063.1

Table 3.13.2 presents the employments levels and earnings for just the household laundry portion of the appliance industry from 1994-2007[o]. Statistics for both employment levels and payroll show a steady fluctuation over the past 14 years, with payroll and employment levels again showing a positive correlation.

Table 3.13.2 Household Laundry Industry Employment and Earnings [38]

Year	Production Workers (‘000)	All Employees (‘000)	Payroll for All Employees (2007$ Mil)
2007	10.3	11.1	415.1
2006	12.4	14.1	587.8
2005	12.6	14.5	549.2
2004	12.9	15.1	606.9
2003	13.1	15.5	645.8
2002	13.5	15.9	711.8
2001	12.8	14.9	633.9
2000	13.3	15.5	681.6
1999	14.0	15.9	678.3
1998	14.3	16.7	702.0
1997	12.9	14.8	603.0
1996	12.9	15.7	640.4
1995	12.9	16.3	678.7
1994	12.9	16.2	714.4

Table 3.13.3 shows the employment levels and payroll for the air conditioning and warm air heating and commercial/industrial refrigeration equipment industry. Industry statistics show a steady decrease in the levels of employment and payroll, and the same correlation between these parameters as seen in the appliance industry.

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[o] Data for 2008 was withheld from the U.S. Census Bureau ASM to avoid disclosing data for individual companies.

Table 3.13.3 Air-Conditioning & Warm Air Heating & Commercial/Industrial Refrigeration Equipment Industry Employment and Earnings [39]

Year	Production Workers *('000)*	All Employees *('000)*	Payroll for All Employees *(2008$ Mil)*
2008	70.8	96.5	4,010.0
2007	74.7	101.5	4,120.2
2006	74.9	98.1	4,224.6
2005	75.9	102.2	4,271.7
2004	73.1	99.0	4,137.8
2003	77.5	104.7	4,353.6
2002	80.4	108.3	4,493.6
2001	89.0	118.9	4,727.6
2000	98.0	127.4	5,222.9
1999	95.9	124.0	5,054.9
1998	92.0	120.0	4,877.5
1997	91.0	119.4	4,720.1
1996	104.0	134.9	5,849.8
1995	103.2	134.8	5,723.0
1994	99.1	130.6	5,572.9

Table 3.13.4 presents the costs of materials and industry payroll as a percentage of value of shipments from 1994–2008. The cost of materials as a percentage of value of shipments has fluctuated slightly over the 15-year period. DOE notes that fluctuations in raw material costs are common from year to year. The cost of payroll for production workers as a percentage of value of shipments has declined since 2000. Similarly, the cost of total payroll as a percentage of value of shipments has declined since 2000.

Table 3.13.4 Household Appliance Industry Census Data[40]

Year	Cost of Materials as a Percentage of Value of Shipments *(%)*	Cost of Payroll for Production Workers as a Percentage of Value of Shipments *(%)*	Cost of Total Payroll (Production + Admin.) as a Percentage of Value of Shipments *(%)*
2008	58.5	7.7	10.5
2007	57.8	8.0	10.5
2006	57.9	8.4	10.9
2005	56.9	8.3	11.0
2004	57.2	9.0	12.1
2003	55.9	9.2	12.5
2002	54.9	9.7	13.4
2001	56.8	10.1	13.8
2000	55.8	10.2	14.0
1999	54.7	10.2	13.9
1998	56.0	10.0	13.7
1997	52.8	9.9	13.6
1996	56.8	9.9	13.9
1995	57.7	9.4	13.7
1994	55.5	9.2	13.1

Table 3.13.5 shows the cost of materials and industry payroll as a percentage of value of shipments for the household laundry industry from 1994-2007[p]. DOE observed a decline in both the cost of materials and payroll as a percentage of value of shipments from 1996–2005. However, from 2005-2007, the cost of materials and payroll for production workers as a percentage of value of shipments has increased. Table 3.13.6 shows the trends for the air conditioning and warm air heating and commercial/industrial refrigeration equipment industry, which showed decreases in percentages of both cost of material and payroll from 1996-2005. However, from 2005-2008, the cost of materials as a percentage of value of shipments has increased, whereas the cost of payroll as a percentage of value of shipments has remained relatively constant.

[p] Data for 2008 was withheld from the U.S. Census Bureau ASM to avoid disclosing data for individual companies.

Table 3.13.5 Household Laundry Industry Census Data [41]

Year	Cost of Materials as a Percentage of Value of Shipments *(%)*	Cost of Payroll for Production Workers as a Percentage of Value of Shipments *(%)*	Cost of Total Payroll (Production + Admin.) as a Percentage of Value of Shipments *(%)*
2007	60.1	8.2	9.4
2006	61.2	9.0	11.1
2005	52.5	7.8	9.9
2004	52.5	8.5	11.1
2003	56.0	9.4	12.3
2002	56.6	10.4	14.2
2001	56.2	9.2	11.9
2000	54.2	9.7	12.9
1999	51.4	10.0	12.7
1998	54.5	10.3	13.3
1997	56.1	10.6	12.9
1996	64.4	10.6	13.5
1995	62.3	10.5	14.7
1994	63.4	10.4	14.6

Table 3.13.6 Air Conditioning & Warm Air Heating & Commercial/Industrial Refrigeration Equipment Industry Census Data[42]

Year	Cost of Materials as a Percentage of Value of Shipments *(%)*	Cost of Payroll for Production Workers as a Percentage of Value of Shipments *(%)*	Cost of Total Payroll (Production + Admin.) as a Percentage of Value of Shipments *(%)*
2008	56.7	8.4	13.9
2007	57.7	8.5	13.9
2006	53.2	8.9	13.8
2005	55.3	8.7	14.1
2004	53.3	9.2	14.8
2003	52.5	9.9	16.0
2002	51.3	10.2	16.5
2001	54.8	10.3	16.5
2000	56.3	10.7	17.0
1999	55.9	10.2	16.1
1998	58.1	10.5	16.3
1997	56.7	10.6	16.8
1996	62.0	12.0	17.6
1995	62.7	12.3	18.1
1994	59.5	12.4	18.3

Table 3.13.7 presents the industry cost structure derived from SEC 10-K reports of publicly-owned home appliance manufacturers which produce residential clothes dryers and room air conditioners. DOE averaged the financial data from 2002–2007 of several companies to obtain an industry average. Each financial statement entry is presented as a percentage of total revenues.

Table 3.13.7 Industry Cost Structure Using SEC Data

Financial Statement Entry	Percent of Revenues *(%)*
Cost of sales	81.3
Net income	1.7
Selling, general and administrative	12.8
Capital expenditure	3.3
Research and development	2.3
Depreciation and amortization	3.3
Net plant, property and equipment	18.7
Working capital	1.6

Figure 3.13.1 presents the industry-average gross margin over the period from 2002–2007 for the same manufacturers from which the industry cost structure is derived. The slope of the curve indicates the downward cost pressure facing manufacturers.

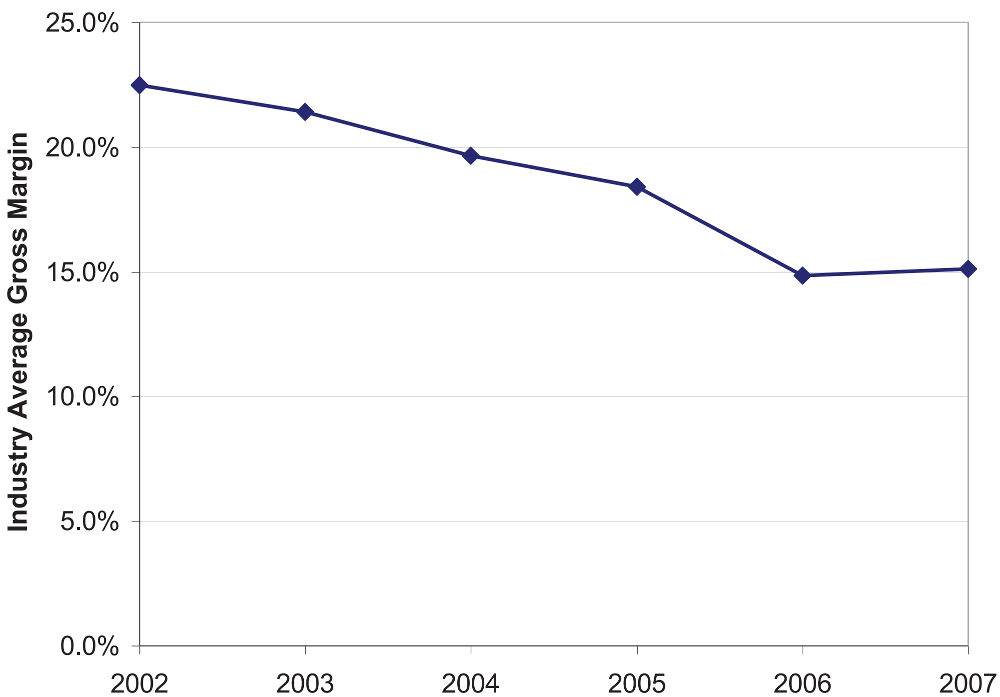


Figure 3.13.1 Industry Gross Margin Derived from SEC Data

3.14 INVENTORY LEVELS AND CAPACITY UTILIZATION RATES

Table 3.14.1 through Table 3.14.3 shows the year-end inventory for the household appliance, household laundry, and air conditioning and warm air heating and commercial/industrial refrigeration equipment industries, according to the ASM. Both in dollars and as a percentage of value of shipments, the end-of-year inventory for these industries has steadily declined since 1995. This data illustrates that domestic manufacturers are retaining less of their inventories each consecutive year.

Table 3.14.1 Household Appliance Industry Census Data[43]

Year	**End-of-Year Inventory** *(2008$ Mil)*	**End-of-Year Inventory as a Percentage of Value of Shipments** *(%)*
2008	1,918.2	8.7
2007	2,040.0	8.4
2006	1,774.0	7.0
2005	1,772.0	6.6
2004	1,959.3	7.3
2003	1,964.0	7.4
2002	2,111.8	8.1
2001	2,347.6	8.8
2000	2,649.0	9.2
1999	2,639.6	9.4
1998	2,845.9	10.0
1997	2,735.3	10.0
1996	3,001.8	10.4
1995	3,315.5	11.1
1994	3,436.4	11.1

Table 3.14.2 Household Laundry Industry Census Data[44]

Year	End-of-Year Inventory *(2007$ Mil)*	End-of-Year Inventory as a Percentage of Value of Shipments *(%)*
2007	258.4	5.8
2006	313.7	5.9
2005	230.5	4.2
2004	211.3	3.9
2003	237.5	4.5
2002	267.2	5.3
2001	310.6	5.8
2000	288.6	5.4
1999	440.9	8.3
1998	449.7	8.5
1997	462.4	9.9
1996	443.5	9.4
1995	423.9	9.2
1994	454.3	9.3

Table 3.14.3 Air Conditioning & Warm Air Heating & Commercial/Industrial Refrigeration Equipment Industry Census Data[45]

Year	End-of-Year Inventory *(2008$ Mil)*	End-of-Year Inventory as a Percentage of Value of Shipments *(%)*
2008	2,888.0	10.0
2007	3,101.5	10.5
2006	3,033.9	9.9
2005	2,903.7	9.6
2004	2,777.3	10.0
2003	2,734.5	10.0
2002	2,711.2	9.9
2001	3,092.3	10.8
2000	3,670.5	11.9
1999	3,687.6	11.8
1998	3,346.5	11.2
1997	3,309.3	11.8
1996	4,007.4	12.0
1995	4,035.8	12.8
1994	3,832.2	12.6

DOE obtained full production capacity utilization rates from the U.S. Census Bureau, *Survey of Plant Capacity* from 1994 to 2006. Table 3.14.4 presents utilization rates for various sectors of the household appliance industry. Full production capacity is defined as the maximum level of production an establishment could attain under normal operating conditions. In the *Survey of Plant Capacity* report, the full production utilization rate is a ratio of the actual level of operations to the full production level. The full production capacity utilization rate for household appliances in aggregate, along with the rates for household laundry appliances, show a decrease in utilization from 1994 to 2006, although trends in subsets of that time period have fluctuated. Full production capacity utilization rates for air conditioning and warm air heating and commercial/industrial refrigeration equipment have remained relatively steady over the period from 1996 to 2006. Prior to 1996, reported data did not disaggregate these types of equipment from more general heating and refrigeration equipment.

Table 3.14.4 Full Production Capacity Utilization Rates[46]

Year	Rates *(%)*		
	Household Appliances	**Household Laundry**	**Air Conditioning & Warm Air Heating & Commercial/Industrial Refrig. Equip.**
2006	77	80	63
2005	74	79	66
2004	76	77	60
2003	78	85	62
2002	72	87	60
2001	70	90	59
2000	70	88	66
1999	75	87	67
1998	73	75	67
1997	73	80	66
1996	76	81	NA*
1995	79	83	NA*
1994	82	89	NA*
* Data not available at this level of disaggregation			

3.15 TECHNOLOGY ASSESSMENT

This section provides a technology assessment for residential clothes dryers and room air conditioners. Contained in this technology assessment are details about product characteristics and operation (section 3.15.1), an examination of possible technological improvements for each product (section 3.15.2) and a characterization of the product efficiency levels currently commercially available (section 3.15.3).

3.15.1 Product Operations and Component

In preparation for the screening and engineering analyses, DOE prepared a brief description of the characteristics and operation of each product covered by this rulemaking. These descriptions provide a basis for understanding the technologies used to improve product efficiency.

3.15.1.1 Residential Clothes Dryers

Residential **clothes dryers** are appliances designed to dry clothes by tumbling the load in a heated drum to remove moisture by means of evaporation. Because a horizontal axis of rotation is required to create the tumble action, residential clothes dryers are generally front-loading. Front-loading clothes dryers have an opening on the front of the unit, covered by a door, which gives access to an inner cylindrical drum where the load to be dried is placed. The inner drum is perforated and is surrounded by a larger outer housing which collects the moisture-laden air. The clothes dryer uses electricity to power an electric motor that rotates the drum within the housing, which is contained inside a cabinet. Vanes and/or surface textures may be incorporated into the inner surface of the drum to facilitate separation of the clothing to expose surface areas for drying.

Air is drawn through the drum by means of an electrically driven blower. This air stream is heated prior to entering the drum in order to evaporate the moisture in the clothing with which the air comes in contact. Heating may be provided by an electrically energized resistive element. Alternatively, hot air in the drum may be supplied by means of a gas burner system whose combustion products are directed into the drum by the electrically powered blower.

In the case of vented clothes dryers, the moisture-laden air is exhausted from the drum through a length of ducting, and as it exits, freshly heated room air is drawn in. The exhaust air is typically vented to an exterior location due to its high temperature and relative humidity. In installations where exterior venting is not possible, a ventless system may be used in which the moist air in the drum is routed through an air- or water-cooled heat exchanger. The water vapor condenses on the heat exchanger surface where it is either collected in a removable container for disposal by the user or discharged into a drain line. Ventless systems may either open-loop, in which the relatively dry air from the drum is exhausted into the room, or closed-loop, in which the dry air is recirculated back to the heater and subsequently to the drum inlet. With an air-to-air heat exchanger, the ambient air that was used to provide cooling is also discharged back into the room at a slightly higher temperature due to the heat transfer from the condensing water. Because the exhaust products from gas combustion systems contain a significant amount of moisture and varying levels of hazardous emissions such as carbon monoxide, ventless clothes dryers are all electrically heated. Tradeoffs associated with ventless versus vented dryers include greater flexibility in installation but longer drying times. In addition, for air-to-air systems, space conditioning loads may be increased due to the discharge of warm dry air to ambient. This may be offset, however, by the fact that conditioned ambient air is not being discharged to the exterior, as would be the case for a vented unit.

Combination washer/dryers combine clothes washing and drying functions in the same front-loading tub. The wash and dry cycles are performed in sequence. Since the washing function requires a drain hookup, and because these units are often installed where space is at a premium and outside access might not be available, all combination washer/dryers currently on the market utilize condensation drying. In addition, a water-cooled heat exchanger is made possible due to the water hookup already in place for the washing.

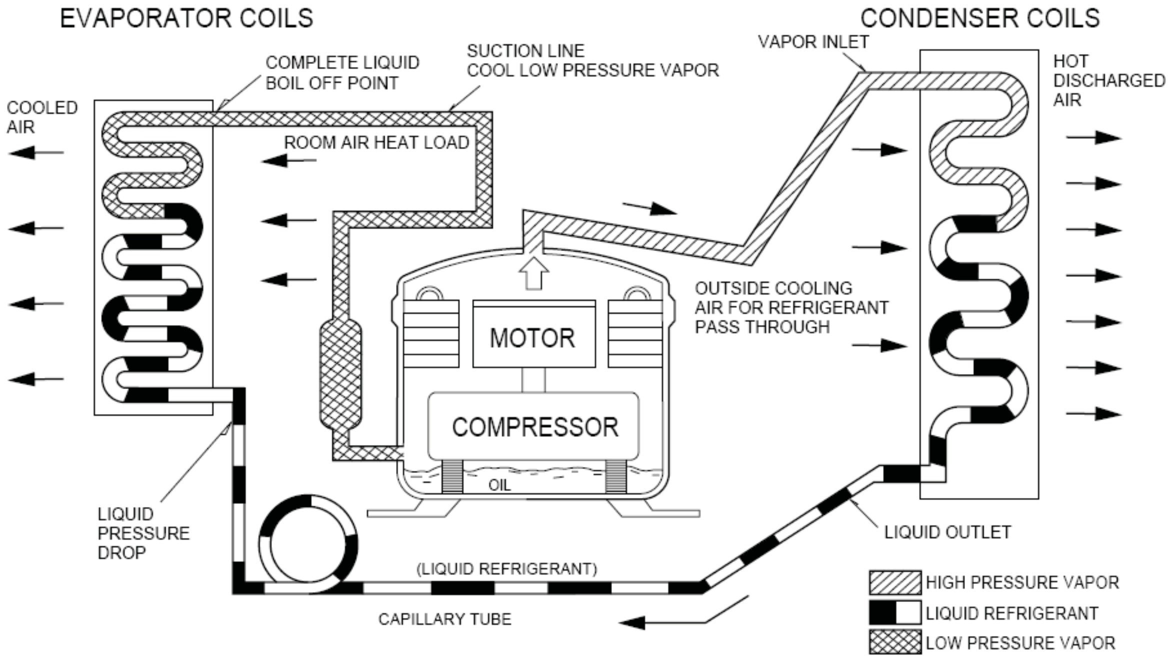
3.15.1.2 Room Air Conditioners

Room air conditioners are portable, refrigeration-based appliances that enable users to cool or warm an enclosed space, room, or zone. In addition to the primary cooling or warming function, room air conditioners also reduce the relative humidity (RH) of the conditioned space. RH is defined as the amount of water vapor present in the air compared to the maximum amount of water vapor the air can hold at that temperature, these amounts being expressed as partial pressures of the water vapor. Although they are portable, room air conditioners are designed for semi-permanent installation in a window opening or opening in an exterior wall. Room air conditioners are classified according to the amount of heat that can be removed from the room air during a given time period, called the capacity, expressed in Btu/h.

Room air conditioners contain refrigeration systems that remove both sensible and latent heat (*i.e.*, thermal load associated with water vapor in the air), from room air. The refrigerant-side and air-side components are all contained within one cabinet. The refrigerant-side components include the evaporator (indoor conditioning coil), the compressor, the condenser (outdoor coil), and the capillary tube. These components are all connected with refrigerant tubing. The air-side components consist of the fan motor, the evaporator blower, and the condenser fan. The cabinet containing both refrigerant-side and air-side components is split into an indoor and outdoor side. An insulated divider wall separates the two sides and reduces the heat transfer between sides. The indoor components are the evaporator and evaporator blower. The outdoor components are the compressor, condenser, capillary tube, fan motor, and condenser fan. A single fan motor with a shaft which extends out both ends is generally used to power both the evaporator blower and the condenser fan. The motor is located on the outdoor side to isolate motor losses from the indoor side. The evaporator blower shaft penetrates the insulated dividing wall.

Refrigeration-based room air conditioners operate as follows, illustrated in Figure 3.15.1:

1. The fan motor drives the evaporator blower and condenser fan simultaneously;
2. Warm air from the room or space is drawn into the indoor side of the unit across the evaporator coil, where latent and sensible heat is removed, and the cooled, conditioned air is circulated back into the room by the evaporator fan;
3. The heat from the air vaporizes the refrigerant in the evaporator coil. The evaporated refrigerant is compressed by means of the compressor;
4. The heated refrigerant is circulated through the condenser coil on the outdoor side of the unit, wherein the vapor is cooled by outdoor air being drawn across the coil by means of the condenser fan. This cools the vapor to saturation conditions and then condenses the refrigerant.
5. The cooled liquid passes through the capillary tube, reducing its pressure. The refrigerant flashes to a liquid/vapor mixture, and the temperature drops, consistent with the pressure/temperature curve of saturated refrigerant. The two-phase refrigerant re-enters the evaporator and the cycle is repeated.



Source: Friedrich CP10E10 Service and Parts Manual[47]

Figure 3.15.1 Room Air Conditioner Operation Schematic

3.15.2 Technology Options

In order to gain a deeper understanding of the technological improvements used to increase the efficiency of residential clothes dryers and room air conditioners, DOE identified several possible technologies and examined the most common improvements used in today's market.

3.15.2.1 Residential Clothes Dryers

For **clothes dryers**, DOE will consider technologies identified in the November 1994 ANOPR (59 FR 56423), supplemented by technologies described in recent trade publications, research reports, and manufacturer product offerings. DOE took the technologies listed below (Table 3.15.1)—with exceptions noted below—from the November 1994 ANOPR. DOE took the modulating gas dryer technology from an April 2005 report by TIAX LLC (TIAX).[48] Additionally, DOE's preliminary market research indicated the availability of hydronically heated clothes dryers, so DOE has decided to include them in the clothes dryer heat generation technologies, but notes that significant revisions to the clothes dryer test procedure would be required to accommodate them. Specifically, DOE would have to incorporate a number of assumptions about the efficiency of the heat generation source used with these dryers. Improved air circulation, motor efficiency, and fan efficiency were added as technology options based on comments received during the Framework Document public meeting for this rulemaking held October 24, 2007 as well as submitted written comments in response to the framework document. DOE also added technology options for reducing standby power, including switching power supplies and transformerless power supplies with auto-powerdown, based on its reverse engineering analyses.

Table 3.15.1 Technology Options for Residential Clothes Dryers

Dryer Control or Drum Upgrades
1. Improved termination
2. Increased insulation
3. Modified operating conditions
4. Improved air circulation
5. Reverse tumble
6. Improved drum design
Methods of Exhaust Heat Recovery (Vented Models Only)
7. Recycle exhaust heat
8. Inlet air preheat
9. Inlet air preheat, condensing mode
Heat Generation Options
10. Heat pump, electric only
11. Microwave, electric only
12. Modulating Heat
13. Water-cooling, ventless electric only
14. Indirect heating
Component Improvements
15. Improved motor efficiency
16. Improved fan efficiency
Standby Power Improvements
17. Switching Power Supply
18. Transformerless Power Supply with Auto-Powerdown

The technology options for residential clothes dryers can be broadly grouped into five main categories: dryer control or drum upgrades, methods of exhaust heat recovery (for vented models only), heat generation options, improvements to components, and options to reduce standby power.

Improved termination

The standard dryer is assumed to use a timed drying cycle, which automatically turns off the dryer after a user-specified time interval. With automatic termination by temperature sensing, an exhaust air temperature sensor controls the length of the drying cycle. With automatic termination by moisture sensing, the moisture content of the clothes in the dryer is determined by sensors that measure conductivity along with an exhaust air temperature sensor. When the moisture content is reduced to a level at which these sensors cannot measure accurately (generally around 15 percent RMC) a countdown timer is started. After a pre-specified time period that is set by the manufacturer, the cycle terminates. Manufacturers indicated in discussions with DOE that moisture sensing with electromechanical controls increase the accuracy above automatic termination using only temperature sensors. Manufacturers stated that moisture sensing with electronic controls further improves the accuracy of automatic termination.

One method to improve automatic termination via moisture sensing is to improve the accuracy of the conductivity sensors at low levels of RMC. This can be done by increasing the contact area between the sensor and the clothing, as achieved by one manufacturer by including slip rings in the drum design. An adjustable gain control can also be used in the electronics to improve the sensitivity; however, this adds significant cost and reliability issues. A second method to improve automatic termination is to improve the accuracy of end-of-cycle detection. One manufacturer has indicated preliminary energy savings of up to 17 percent through timer controls based on new dryer process modeling.[49]

The test procedure for dryers allows an energy credit of 12 percent for either temperature or moisture sensing relative to time control to terminate drying. There has been some controversy as to whether the use of moisture sensors reduces energy consumption relative to temperature sensors. A number of sources claim that temperature sensing controls provide 10 percent real-world energy savings, whereas moisture sensing controls provide 15 percent energy savings.[50] Based on field measurements conducted by one manufacturer for the previous rulemaking, it appears that the test procedure credits are appropriate.

Increased insulation

During the drying cycle some parts of the dryer are warmer than the ambient air. Insulating the dryer drum reduces the heat lost through conduction, convection, and radiation to the surrounding air. During the previous rulemaking, two dryer manufacturers reported an energy savings of about 2 percent from the addition of 1 inch of fiberglass insulation around the dryer drum. Computer simulations performed by other researchers with a thermal model showed a 6 percent energy savings.[51] However, in recent discussions with DOE, manufacturers indicated that there is little to no efficiency improvement associated with adding insulation.

There is concern that the insulation would eventually degrade, resulting in fiberglass particles being drawn into the drum and onto the clothes because dryer air circulation systems operate with a negative air pressure in the drum relative to the outside. These particles can cause skin irritation. Potential material substitutions for fiberglass include polystyrene, polyethylene, or polyurethane foam insulation. They have similar or lower thermal conductivities and do not cause skin irritation.

Modified operating conditions

Reducing air flow and/or heat input rate changes the efficiency of the drying process. Manufacturers may select operating points which match the dryer cycle time to the washer cycle time. From an efficiency standpoint, these settings do not necessarily lead to optimum dryer operation. By decreasing the air flow rate, the air temperature in the drum, and thus the evaporating rate, increases and results in better energy efficiency. Energy savings of as much as 8 percent have been shown for tests with reduced air flow rates and electric heater inputs, but the drying time increased from about 40 to 55 minutes. Tests by the same researchers with only reduced heater input (3.3 kW instead of 4.55 kW) yielded no energy savings and increased the drying time from 40 to 56 minutes. For a very low heater input (1.25 kW), energy savings of around 5 percent were achieved, but the drying times were very long (112 minutes).[52]

Improved air circulation

One manufacturer of commercial clothes dryers has claimed that designing the drum to improve airflow (*i.e.,* directing and maintaining heat more efficiently) decreases the energy use while maintaining the drying performance.[q] However, DOE is unaware of any data quantifying the energy savings associated with improved air circulation.

DOE noted that air flow through the drum in conventional dryers is generally directed from the rear to the front of the drum. Based on discussions with a number of manufacturers, a small efficiency improvement, between 1 and 2 percent, can be achieved by changing the air flow in the drum such that the air flows in through one side on the rear of the drum, and exits on the other side of the rear of the drum.

Dryer booster fans can be installed to increase the airflow in clothes dryers, which conceivably increases the rate of forced convection. In cases of long exhaust ducting where the static pressure that must be overcome by the dryer fan is increased, incorporating a dryer booster can increase the airflow and thus increase drying capacity and reduce energy consumption of the clothes dryer. However, the current DOE clothes dryer test procedure uses an exhaust simulator with a standard length and geometry and does not account for alternate installation conditions. DOE is unaware of any data quantifying the energy savings associated with dryer booster fans.

Reverse tumble

Reverse tumble drying spins the drum in both the clockwise and counter-clockwise directions. This action is typically carried out at the end of the cycle in order to reduce the amount of wrinkling and tangling of the clothes. However, it is possible to reverse rotational direction earlier in the cycle to increase the separation of clothing and thus dry the clothes load more quickly and evenly. In the description of a patented reverse tumbling method, it is claimed that a 10 percent reduction in drying time, and thus energy consumption, could be achieved.[53] In addition, reversing the drum rotation can prevent "balling" of large items such as sheets, which restricts air flow to the center of the item and requires longer drying times. No manufacturer indicated they use, or would consider, reverse tumble for increasing efficiency. Tests conducted by one manufacturer, however, found that the small size of the test cloths in the DOE test procedure prevents balling and thus no energy efficiency benefit can be measured.[54] Manufacturers also noted in discussions with DOE that reverse tumble does not improve efficiency, and in some cases can reduce efficiency when the drum is not rotating while it is changing directions.

Improved drum design

The intrinsic energy efficiency of a clothes dryer can be affected by the design of the drum, including the internal vane design.[55] Optimized vane design promotes clothing separation during tumbling, which can reduce drying times. According to some manufacturers, the surface

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[q] For more information visit *www.amdry.com/resources/products/450264%20Solaris%206_06_final.pdf*

texture of the drum can also enhance clothing separation. Manufacturers noted that such designs are performance related features to ensure gentle handling of delicate clothing, but conceivably the improvements in clothes separation and aeration could shorten drying times as well. However, DOE is unaware of any data quantifying potential energy efficiency improvements associated with improved drum design.

Recycle exhaust heat

It is estimated that about 20–25 percent of total heat input energy is lost through the dryer vent. For the recycle exhaust heat technology option, a portion of the exhaust air stream is reintroduced at the dryer air inlet. This recovers a portion of the energy in the exhaust air stream and reduces the energy needed to raise the inlet air to drying temperatures. The exhaust air suitable for direct recovery would be available only late in the drying cycle when most of the moisture is evaporated and the air temperature rises. Therefore, the realizable energy savings are significantly less than the theoretical maximum of about 20 percent. The estimated energy use reduction for this technology option is 6 percent.

Recycling of exhaust air late in the dryer cycle can be accomplished using extra duct work and mechanical air diverters; however, it presents several technical problems. There is the potential for lint accumulation in the duct work and on the clothes. Recycling of exhaust air could present a potential fire hazard since some large pieces of lint could enter the heated area. For a gas dryer, there is also a potential inability to promote satisfactory combustion.

Experiments performed with a 230 V electric dryer (with a baseline energy use of over 3.0 kWh/cycle) showed that energy savings ranged from 10 to 18 percent, depending on the fraction of exhaust air recirculated.[56] A fine nylon-mesh filter was installed to minimize the amount of recirculated lint. These energy savings are greater than one would expect given the large quantity of moisture in the exhaust early in the cycle. Additionally, the National Institute of Standards and Technology (NIST) testing indicated savings ranged from 3 to 6 percent for this option.[57]

Inlet air preheat

For this technology option, a heat exchanger is used to recover exhaust heat energy and to preheat inlet air. This system should be feasible for both gas and electric dryers since none of the exhaust air re-enters the dryer. Energy savings are achieved either by a faster drying time or by reducing the required heater input power. A number of researchers have investigated this technology option for clothes dryers. One manufacturer has estimated 2 to 3 percent energy savings, while NIST estimated 3 to 6 percent.[58] Both of the above experiments were carried out in the non-condensing mode. That is, moisture in the exhaust air was not condensed, which limited the maximum heat recovery.

A limitation of this technology option is that a large surface area is required to achieve sufficient heat transfer, and that lint may accumulate on these heat transfer surfaces. Although every dryer is equipped with a lint filter, considerable lint is still contained in the exhaust air. This lint can foul the heat exchanger, decreasing its effectiveness. Additionally, to overcome the increased resistance to air flow, an extra blower is needed at the fresh air inlet or a stronger blower in the exhaust air duct is required.

Manufacturers have also expressed concern that any decrease in exhaust temperature will lead to moisture condensation in the exhaust duct, which could result in damage to the exhaust duct and dryer, as well as water leakage into the home. Water leakage into the home could lead to the health risks from the development of mildew and/or mold.

Inlet air preheat, condensing mode

Dryers have been manufactured both in the United States and Europe that utilize a condenser to capture some of the sensible and latent heat in the exhaust air stream. For this technology option, heat energy from the exiting air is transferred, using a heat exchanger, to the cooler incoming air. If the effectiveness of the heat exchanger is high enough, the water vapor in the exhaust air will condense. Therefore, more heat energy is transferred than in a sensible heat exchanger system as described above. In Europe, condenser dryers have been used in an open system to supply space heat during the winter. In the United States, they have been used to avoid the need for vents in apartments. Research has shown that compared to a conventional air vented dryer, an open-cycle condensing dryer is about 14 percent more efficient and a closed-cycle condensing dryer is 7 percent more efficient.[59] Manufacturers have indicated that only minimal (1 to 3 percent) efficiency improvement can be achieved with inlet air preheat.

Manufacturers have identified several problems with this technology option: 1) a drain for the moisture is required; 2) lint accumulation on the heat exchanger reduces the heat transfer efficiency; and 3) lint can accumulate and clog the drain. Because a drain is required to be installed, and humid operating conditions require extensive use of stainless steel or glass in the heat exchanger to avoid corrosion, manufacturer cost for this technology option will be greater than for the inlet air preheat with a sensible heat exchanger.

An alternative approach to capture heat from the exhaust air stream is to mechanically compress the exhaust air to extract water vapor and transfer the latent heat to the remaining gaseous steam. The extracted water is drained from the compression chamber, and the pressurized gaseous steam is allowed to expand and be superheated before being injected back into the drum to help preheat the inlet air. Researchers have claimed that such a compression condenser dryer is as energy efficient as a heat pump dryer, but has almost half the cycle time and requires fewer specialized components.[60]

Heat pump, electric only

Heat pump dryers function by recirculating the exhaust air back to the dryer while moisture is removed by a refrigeration-dehumidification system. A heat pump dryer is essentially a dryer and an air conditioner packaged as one appliance. No heating element is needed. The warm and damp exhaust air of the dryer enters the evaporation coil of the dehumidifier where it cools down below the dew point, and sensible and latent heat are extracted. The heat is transferred to the condenser coil by the refrigerant and reabsorbed by the air, which is moving in a closed air cycle. A drain is required to remove the condensate; however, one is usually available since clothes washers and dryers are typically located side by side. Heat pump dryers have been unable to penetrate the market despite showing significant energy savings (in some cases over 50 percent compared to electric resistance dryers), even in Europe, where they have been in existence for years. Based on a recent study, heat pump dryers had a market share of only 0.3 percent in Western Europe in 2005.[61] The major issue for heat pump dryers has been cost and performance. Heat pump dryer dry times are typically significantly longer than those associated with standard U.S. electric dryers.

A heat pump dryer has been developed by a U.S. company which has successfully tested several prototypes and found energy savings of 68 percent as compared to energy use by a conventional electric clothes dryer. The estimated retail cost is approximately twice that of a conventional electric dryer. Drying times were essentially the same as for the conventional dryer, and the dryer operates on standard 120 V line power. The prototype uses a disposable filter to reduce lint in the air system. One inch of polyisocyanurate insulation was used to avoid condensation of water vapor in the recirculated air. In addition, the extension on the back of the prototype dryer to accommodate the added refrigeration components was estimated to be about the same depth as a vent duct, so the cabinet may fit in the same space as a conventional dryer.

More maintenance will probably be required for a heat pump dryer than for a conventional dryer. The heater is replaced by equipment found in a small room air conditioner—a condenser, evaporator, compressor, expansion valve, etc. Installation costs, though, may be less than for a conventional electric dryer because the heat pump dryer does not require an exhaust vent as does a conventional dryer (although some heat pump dryers may still use a vent). However, heat pump dryers require access to a drain for removal of condensate.

Research conducted on both heat pump dryers and conventional vented dryers on the European market showed that heat pump dryers consumed about 50 percent less energy than conventional dryers. The heat pump dryers tested had energy efficiency values between 0.32 and 0.40 kWh/kg laundry (with 70 percent initial moisture, measured according to test standard EN 61121) whereas conventional dryers had values between 0.6 and 0.8 kWh/kg laundry. Another benefit noted by this research was that the leakage of water vapor into the room was around 20 percent, which is significantly lower than conventional dryers. This research performed a cost comparison of heat pump dryers versus conventional dryers, which showed that the combined sale price and electricity costs over 15 years was about 1900 and 2300 Euros, respectively.[62]

Research sponsored by TIAX and Whirlpool developed a high efficiency, high-performance heat pump clothes dryer for the U.S. market. This different approach to the heat pump system maximized the output capacity and temperature from the heat pump. This design has shown 40 to 50 percent energy savings on large loads along with 35 degree Fahrenheit (°F) lower fabric temperatures and similar dry times. For delicate loads, the design reduced fabric temperature by 10–30 °F and provide up to 50 percent energy savings and 30–40 percent drying time savings. The heat pump dryer designed by TIAX also exhibited improved fabric temperature uniformity as well as robust performance across a range of vent restrictions in a partially open-loop design described below.[63]

In order to maximize the air inlet temperature and airflow into the dryer's drum, TIAX replaced the standard refrigerant, R-22, with R-134a in an R-22 air conditioner/heat pump compressor, shifting evaporating and condensing temperatures by 30 °F while maintaining similar operating pressures and power input. TIAX was also able to maximize the capacity of the heat pump system by redesigning the heat exchanger components to optimize space utilization and increasing the airflow in the system as compared to typical dryers.[64]

A key issue in the TIAX design was the venting options of the heat pump dryer. The moisture in the air exiting the drum is removed by the evaporator. This air can then be recirculated back into the drum, which removes the need for a vent. However, some form of heat rejection is required since the heat pump generates more heat than cooling in steady state operation. TIAX used a partially open-loop design in which a portion of the process air is vented outdoors to remove excess heat. In this design, all of the process air is recirculated through the dryer until the system has fully warmed, at which point the exhaust is opened and a portion of the total flow is vented to the outside.[65]

Microwave, electric only

Microwave energy can be absorbed by water, thereby heating the water enough to cause evaporation. This would be a direct and efficient manner to remove moisture from clothes. Prototype microwave dryers have been built and tested. The previous rulemaking determined that energy savings from the use of a microwave dryer would be approximately 26 percent compared to a conventional dryers. The data was provided by a company developing a prototype microwave dryer, and the developers claimed that the system could safely dry clothes with metal buttons and zippers, although clothes with metallic threads could be damaged. Uniform drying is also a problem since the microwaves may not reach the interior of the clothing container. The prototype dryer described above utilized two magnetrons for delivering the microwave energy to the drum.

Instead of the conventional method of passing warm air over the clothes, microwave energy can be directly absorbed by water retained in the clothing, thereby heating the water enough to cause evaporation. Microwave drying uses the principle of dielectric heating, in which electromagnetic energy is radiated into the dryer drum where it is absorbed by water molecules which have a higher dielectric loss factor than most common fabric materials. Most fabric materials are also relatively transparent to microwave energy, so that the microwaves can penetrate the fabric's interior to heat the water molecules directly. This allows the fabric in a microwave dryer to stay cooler—below 115 °F—as compared to conventional dryers which heat air to approximately 350 °F, with fabric surfaces reaching 150 °F. Microwave dryer prototypes have been shown to consume about 17 to 25 percent less energy as well as to dry clothes about 25 percent faster than conventional electric dryers.[66]

Early conceptualization of this technology began in the mid-1960s; however, product development was not pursued because of high manufacturing costs and difficulties in overcoming hazards relating to arcing and overheating of clothing. In 1997, the Electric Power Research Institute (EPRI) focused on developing a compact countertop dryer based on economic feasibility and market surveys. EPRI market studies and the development of prototypes for in-house evaluation have led to negotiations for technology licensing and indications of serious product development for a residential microwave clothes dryer.[67]

Because of the interaction between the metallic sensor contacts and the electromagnetic field, microwave dryers are incapable of using contact moisture sensors as in conventional dryers. EPRI investigated using sensors to detect the microwave electric field strength and the fabric temperature, which both correlate well with the moisture content. As evaporation nears completion, both measured signal slopes begin to rise in a predictable manner, so that the dryer can be shut off automatically and avoid wasted energy in over-drying clothes.[68]

Microwave drying also introduces a safety concern related to arcing. Arcing is caused by an electric field which induces a voltage differential between metal objects, allowing current to flow within them. The resultant heating and sparking of the metal objects may ignite a fire in the load. EPRI has developed a rapid-response gas sensor to detect small amounts of gaseous by-products of combustion in the exhaust stream. Upon detection, the drying cycle can be shut down immediately, preventing safety hazards and damage. Another technique to avoid arcing is to switch to electric resistance heaters when the clothes are almost dry.[69]

Modulating Heat

Most gas dryers on the market operate with a single burner at a fixed input rate and a fixed airflow rate in an on/off mode based on the cycle chosen and the temperature of the exhaust flow. Based on a modulating gas dryer design jointly developed by TIAX and Whirlpool, a reduction of energy consumption of up to 25 percent for small and medium loads has been shown. For large loads, a reduction in energy consumption of 10–15 percent has been shown as well as up to 35 percent drying time savings, with no adverse effect on cloth temperature. For delicate loads, modulating gas dryers are able to reduce fabric temperatures as well as dry times, achieving an 18 percent reduction of energy consumption. Along with these performance characteristics, modulating gas dryers would provide robust performance across a range of vent restrictions.[70]

A key consideration in the design of a modulating gas dryer is matching the heat input rate to the moisture level of the load. The design developed by TIAX used a maximum gas input rate of 40,000 Btu/h using two inshot burners firing into a combustion chamber that was larger than in a conventional gas dryer. The gas input rate was able to be modulated to three different levels: (1) high (40,000 Btu/h), (2) medium (rate similar to conventional gas dryers), and (3) low (rate less than half of a conventional gas dryer). The burners were positioned so that they fired into an oval-shaped combustion funnel before turning upwards into the rear duct and entering the drum. A downstream blower was used to induce airflow into the drum. A new funnel/collar/rear duct was designed to deliver evenly distributed and improved air flow to increase efficiency, while being able to be manufactured with minimal modifications to existing plant tooling.[71]

TIAX utilized a variable speed blower to deliver varying airflow rates to match the following general dryer cycles: (1) heavy duty, (2) normal, and (3) delicate. In order to account for airflow changes and resultant pressure drops associated with installation variations, the system used a pressure switch in the exhaust flow stream from the dryer. The blower speed would be increased at the beginning of the dry cycle until the pressure switch was tripped, providing an indication of the level of exhaust restriction.[72]

Control of this system was achieved via a temperature and humidity sensor in the exhaust. Since the flow rate would be known, the temperature in the exhaust would be used to infer the amount of moisture inside the drum. The temperature signal would thus be used to determine when to perform the first and second modulation steps. In addition, this temperature signal, combined with the output from a humidity sensor in the exhaust, could be used to determine the end of the cycle.[73]

Modulating heat can also be implemented in an electric clothes dryer. The electric resistance heater could be accurately controlled by an electronic controller that incorporates a bidirectional triode thyristors (Triacs) or similar solid-state approaches to control the heat output.

Water-cooling, ventless electric only

For this technology option, an internal water-cooled condenser heat exchanger system condenses the water vapor in the air exiting the drum. This design is similar to conventional condenser heat exchanger systems used in clothes dryers in which the exhaust heat is recirculated back to the dryer, except that the cooling fluid is water, not air. On the market in Australia, water-cooled condensers are generally used in combination washer/dryers whereas air-cooled condensers are used in stand-alone dryers. According to a report prepared for the Department of the Environment and Water Resources in Australia, for combination washer/dryers using water-cooled condensers, the amount of water required for condenser cooling can be as much or more than as is used for the wash cycle.[74] In addition, this technology option would require a drain for the removal of condensate as well as plumbing to the supply water. DOE is unaware of any data quantifying potential energy efficiency improvements associated with improved drum design.

Indirect heating

For indirect heating, the clothes dryer heat energy is derived from the home’s heating system. This technology option uses a residence’s hydronic heater system to heat water which then flows through a heat exchanger in the dryer, heating the air entering the drum. Significant plumbing would be required to circulate heated water through the heat exchanger in the dryer. DOE is unaware of any data quantifying potential energy efficiency improvements associated with indirect heating.

It is possible that a stand-alone hydronic heater could be implemented as a clothes dryers heat source. One source claims that water or other heat transfer fluids could be heated using an immersion element similar to a water heater. The heated fluid passes through a heat exchanger, where the heat is transferred to the air entering the drum, and is then pumped back to the hydronic heater. The source claims that a hydronic heating clothes dryer uses 50 percent less energy and dries the clothing load up to 41 percent faster than conventional clothes dryers.[75]

Improved motor efficiency

Clothes dryers generally use a single motor which functions to turn the drum as well as to power the blower in order to draw air through the drum and out the exhaust vent. The typical clothes dryer uses a 1/3 horsepower four-pole induction motor. Based on DOE testing, about 5 percent of the total electrical energy consumed by a typical clothes dryer is used by the electric motor to drive the drum and the blower. Manufacturers stated that improving the efficiency of the motor can increase overall efficiency by 1 to 5 percent. Manufacturers also indicated that using an electronically-commutated motor (ECM) is very expensive and provides minimal efficiency improvement.

A number of manufacturers indicated that they use separate motors to drive the drum and the blower fan with a permanent split capacitor motor or brushless permanent magnet motor in some models in order to adjust air flow rates based on different exhaust vent installations to improve performance. However, they indicated that because the DOE test procedure uses a standard exhaust simulator (as indicated above), there would be no benefit to efficiency. DOE believes that such a split motor design which can adjust air flow rates implemented designs such as a modulating heater could conceivably improve efficiency.

Improved fan efficiency

Clothes dryers generally use an electrically driven fan blower to draw air through the drum. Increasing the efficiency of this blower could reduce the clothes dryer energy consumption. A blower fan with rear curved blades (as opposed to conventional forward curved blades) could conceivably provide more consistent air flow and improve efficiency. However, DOE is unaware of any data quantifying the potential energy efficiency improvements associated with an improved blower fan, distinct from improvements in its drive motor.

Switching Power Supply

A potential area for standby power improvement is the power supplies on the control board. A typical clothes dryer may use an unregulated plus regulated control board power supply (also referred to as a linear power supply). The unregulated portion consists of a small transformer, a bridge rectifier, and an electrolytic capacitor. Voltage regulators then step down the voltage(s) to the level(s) required by the control logic, display, and cooking sensor. This approach results in a rugged power supply which is reliable, but typically has an efficiency of about 55 percent.

Switching power supplies offer the highest conversion efficiencies (up to 75 percent) and lowest no-load standby losses (0.2 W or less), though at a higher cost, higher part count, and greater complexity. Switching power supplies convert power differently than conventional linear power supplies. Switching power supplies first rectify the alternating current (AC) mains voltage to direct current (DC), converting it back to AC by switching the current on and off at high frequency. The high-frequency AC current passes through the primary winding of a transformer while the output from the secondary winding of the transformer is rectified, resulting in a low-voltage DC output. Because the AC current passing through the transformer is at high frequency, the transformer is smaller and has lower standby losses. Switching power supplies greater complexity may also result in lower overall reliability and take greater care to implement. For example, among other issues, a switching power supply can be prone to causing electromagnetic interference. However, DOE noted in its reverse engineering teardown analysis that there are a large number of clothes dryers on the U.S. market that incorporate switching power supplies.

Transformerless Power Supply for Auto-Powerdown

DOE's reverse engineering teardown analysis suggests that very low standby levels can be achieved by implementing a transformerless power supply for the microprocessor logic, along with a conventional power supply that is activated when the unit goes into active mode. Such a power supply design, incorporated with a "soft" power pushbutton and triac to control power through the transformer, would provide just enough power through the transformerless power supply to maintain the microcontroller chip while the clothes dryer is not powered on. When the power button is pressed, current would then be allowed to pass through the transformer of the conventional power supply to power the remainder of the control board. DOE is unaware of any data indicating the reliability of such a design.

3.15.2.2 Room Air Conditioners

For **room air conditioners**, DOE considered technologies identified in its last standards rulemaking that culminated in the September 24, 1997, final rule. 62 FR 50122. With the exception of microchannel heat exchangers and hydrophilic-film coating on fins, DOE has determined that the technologies listed in Table 3.15.2 have not changed appreciably since DOE's TSD was published in September 2007. With regard to microchannel heat exchangers, research conducted at the University of Illinois has demonstrated that this technology can be applied to room air conditioner applications.[76] Hydrophilic-film coating on fins was identified in an analysis of energy efficiency in Chinese room air conditioners conducted jointly by Lawrence Berkeley National Laboratory, the China National Institute of Standardization (CNIS), and the Beijing Energy Efficiency Center (BECon).[77]

Table 3.15.2 Technology Options for Room Air Conditioners

Increased Heat Transfer Surface Area	Technology Passed to Screening Analysis?
1. Increased frontal coil area	Yes
2. Increased depth of coil (add tube rows)	Yes
3. Increased fin density	Yes
4. Add subcooler to condenser coil	Yes
Increased Heat Transfer Coefficients	
5. Improved fin design	Yes
6. Improved tube design	Yes
7. Hydrophilic-film coating on fins	Yes
8. Spray condensate onto condenser coil	Yes
9. Microchannel heat exchangers	Yes
Component Improvements	
10. Improved indoor blower and outdoor fan efficiency	Yes
11. Improved blower/fan motor efficiency	Yes
12. Improved compressor efficiency	Yes
Part-Load Technology Improvements	
13. Two-speed, variable-speed, or modulating-capacity compressors	Yes
14. Thermostatic or electronic expansion valves	Yes
15. Thermostatic cyclic controls	Yes
Standby Power Improvements	
16. Switching Power Supply	Yes
Refrigeration System Options	
17. Alternative Refrigerants (R-407C)	No
18. Suction-Line Heat Exchanger	No

As shown in Table 3.15.2, design improvements to improve energy efficiency can be categorized according the following six methods: increasing heat transfer performance by either increasing heat transfer surface area or the heat transfer coefficients, improvements upon individual components, part-load technology improvements, standby power improvements, and refrigeration system options.

Technology options that are intended to improve efficiency under cycling or part-load conditions cannot be evaluated under the current DOE test procedure which specifies steady-state test conditions. Technology options such as variable speed compressors, electronic expansion valves, and cyclic controls improve efficiency in central air-conditioning (CAC) systems. CAC products are rated using a seasonal efficiency metric (the seasonal energy efficiency ratio, SEER), which takes into account the efficiency of the product while operating under part-load conditions. However, CAC operating conditions are different than those experienced by room units. CAC units typically are generally active during the entire cooling season, ready to be turned on by the thermostat when there is a call for cooling. In contrast, room air conditioners are generally turned on when the room temperature is high, thus reducing the amount of cycling as compared to CAC systems. Manufacturers have commented that room air conditioners have become a commodity item that is typically undersized for the room in which it is installed, and thus increasing their tendency to operate mostly in on/off mode. Measurement of part load efficiency has not been integrated into the room air conditioner efficiency metric, because of the low probability that greater use of part-load technologies will be used and/or will save energy. Hence, the potential for energy-savings benefits from technology options that reduce energy consumption during part load conditions cannot be evaluated using the new efficiency metric, CEER, on which the engineering analysis is based.

DOE added technology options 17: R-407C as a refrigerant, and 18: Suction-Line Heat Exchanger (SLHX) in response to stakeholder comments during the preliminary phase of the rulemaking.

Table 3.15.2 indicates which technologies DOE considered suitable for further analysis. These are the technologies that DOE passed to the screening analysis for further review. The reasons that certain technologies were not passed to the screening analysis are provided in the individual technology descriptions below.

Technologies Passed to the Screening Analysis

Increased frontal coil area

One of the most common ways of increasing heat transfer surface area is by using a coil with a larger frontal area. With a greater amount of coil face area, the heat transfer performance of the coil is increased. For the condenser, the required heat can be rejected from the refrigerant to the outside air stream at a lower condensing temperature. For the evaporator, the specified cooling capacity can be delivered to the room at a higher evaporator temperature. These changes reduce the pressure difference between the low pressure and high pressure sides of the system which the compressor must overcome, thus reducing compressor power input. However, a trade-off associated with increased evaporating temperature is that the evaporator's ability to dehumidify the air may be compromised.

Increase of coil frontal area is limited in many situations by the size constraints for the room air conditioner, particularly for large-capacity and through-the-wall products (*i.e.*, products without louvered sides).

Increased depth of coil (add tube rows)

Heat transfer surface area may also be increased by adding rows of tubes to the coil. In the previous rulemaking, manufacturers asserted that each room air conditioner chassis is designed for a maximum-depth evaporator and condenser. Vertical tube rows may be added up to that maximum depth, however adding more rows would require an increase in the size of the chassis, which incurs significant costs beyond just the costs of the larger heat exchanger.

Other issues associated with increase of heat exchanger depth include the need to minimize weight, the added refrigerant charge, decreasing improvement associated which each additional tube row, and the airside pressure drop. With regard to weight, manufacturers claimed that there is a practical limit to the depth of a room air conditioner which is related to weight, appearance, and strength of the mounting. The increase in refrigerant charge combined with the increased effectiveness of the heat exchangers can lead to risk of compressor failure. The room air conditioner may require a smaller-capacity compressor to meet the specified cooling load. Smaller compressors have lower refrigerant charge limitations to avoid problems such as oil frothing during startup, so the changes could impact the reliability of the compressor. Manufacturers asserted in the previous rulemaking that each successive row in a coil is only about 70 percent as effective as the preceding row, thus adding rows to a three- or four-row heat exchanger has a small effect on system efficiency. Finally, increasing heat exchanger depth can reduce air flow, which can negate any benefit associated with the additional heat exchanger surface area.

Increased fin density

Another method of increasing the heat transfer surface area is to increase the fin density. Increased fin density improves the heat transfer; however, its effect on air flow, fan power, water drainage, and dirt build-up places a limit on how much the density can be increased.

Fin density has a direct effect on the fan power required to draw or blow air over the coil. Increasing the fin density increases the air-side pressure drop over the coil, resulting in more power being used by the fan motor. Any reduction in air flow can negate the improvement in heat transfer associated with increased fin density. Increased fin density also can increase water retention in the evaporator. The condensate that forms on the evaporator must flow down to the drain pan by the effect of gravity. Increased fin density can limit the condensate flow, which can restrict air flow and lead to entrainment of water droplets in the discharge air flow. The build-up of dirt on heat exchanger surfaces is accelerated by an increase in fin density. Smaller air passageways through the coils are more likely to retain dirt which, if allowed to accumulate over a unit's life, decrease the system performance. Taking these factors into consideration the maximum fin density is a function of the type of coil (*i.e.*, evaporator or condenser), the fin type (*i.e.*, wavy, louvered, or enhanced), the number of tube rows, and the tube diameter.

Add subcooler to condenser coil

Subcoolers are added between the condenser coil outlet and the capillary tube inlet and are submerged near the condenser in the condensate produced by the evaporator. Adding a subcooler effectively increases the size of the condenser coil as it further cools the refrigerant coming out of the condenser. However, finding the space to incorporate a subcooler into a room air conditioner can be difficult..They are used much more frequently in larger-capacity units, which have more space for them.

In the previous rulemaking, manufacturers supplied data for evaluating subcoolers as a design option. The data from the 1997 TSD analysis is recreated in Table 3.15.3, which shows the manufacturer test results on the performance improvements due to adding a subcooler. Using a representative baseline for each product class, specifications were given on how large a subcooler could be to be incorporated into the existing baseline design. In addition, manufacturers provided test data detailing the effect on capacity, power consumption, and efficiency due to the addition of a subcooler. For each product class, the percentage change in efficiency was used to establish the efficiency gain due to adding a subcooler. Test data was not provided for classes with reverse cycle.

Table 3.15.3 Manufacturer Test Results from 1997 TSD Analysis: Performance Improvements due to Subcoolers

Product Class	Before Subcooler Added		Percent Change with Subcooler Added *(%)*		
	Capacity *(Btu/h)*	**EER *(Btu/W-h)***	**Capacity *(Btu/h)***	**Power *(kWh)***	**EER *(Btu/W-h)***
Louvered side w/o reverse cycle less than 6,000 Btu/h	6,338	9.19	1.0	-2.0	2.9
Louvered side w/o reverse cycle 6,000 to 7,999 Btu/h	7,461	8.50	1.7	-1.3	3.0
Louvered side w/o reverse cycle 8,000 to 13,999 Btu/h	9,984	9.20	-0.8	-1.1	1.0
	11,668	9.00	0.8	-0.9	1.8
Average Change for Product Class:			0.0	-1.0	1.4
Louvered side w/o reverse cycle 14,000 to 19,999 Btu/h	18,351	9.70	2.0	0.0	2.1
	18,984	9.70	1.5	-0.2	1.6
	17,954	9.71	1.1	-0.3	1.4
Average Change for Product Class:			1.5	-0.2	1.7
Louvered side w/o reverse cycle greater than 20,000 Btu/h	24,319	8.00	0.9	-1.0	1.9
	34,947	8.00	0.3	-0.6	1.0
Average Change for Product Class:			0.6	-0.8	1.5
No louvered side w/o reverse cycle 6,000 to 7,999 Btu/h	6,204	8.91	0.5	-1.3	1.8
No louvered side w/o reverse cycle 8,000 to 13,999 Btu/h	11,300	8.51	0.2	-2.6	2.8

A study for the Directorate-General for Energy (DGXVII) of the Commission of the European Communities used a simulation model to calculate the impact of individual technology options on a room air conditioner's performance. The results of the simulation showed that the addition of a subcooler to the condenser coil resulted in a 1 percent average increase in EER.[78]

Improved Fin Design

Improvements to the fin design may have the effect of improving the coil's air-side heat-transfer coefficient, and thus improving the overall heat-transfer capability of the coil. This improvement can be due to the increase in air turbulence over the coil caused by the enhanced fin design. Manufacturers commented in the previous rulemaking that most room air conditioners use some form of fin enhancement in their coil designs already. This fin improvement is generally achieved by using louvered, lanced, or slit-type fin surfaces.

Specific attention to evaporator design regarding condensate runoff and fin patterns may increase room air conditioner energy efficiency. It is useful for the evaporator to be designed such that condensate runs off effectively and does not adhere to the surface. In addition to allowing less entrainment of liquid droplets into the air stream, effective condensate runoff results in higher heat transfer between the evaporator and the air and allows higher air flow, thus increasing evaporator performance.

Improved Tube Design

Improvement of the refrigerant-side heat-transfer coefficient is accomplished by augmenting the inside surface of the refrigerant tubes with spiral grooves. This type of refrigerant tubing is known as rifled or grooved tubing. Research has shown that the refrigerant-side heat-transfer coefficient for grooved tubing is significantly greater than that of conventional smooth tubing. As seen with fin enhancements, manufacturers of refrigerant tubing have developed various types of grooved tubing to improve the heat-transfer capability of air conditioning coils. Improvement to the refrigerant-side heat-transfer coefficient is a function of width, height, and spacing of the grooves as well as the concentration of lubricant oil being circulated within the refrigerant. As discussed in the 1997 TSD, statistical equations have been developed which can predict the benefits of rifling.[79]

Hydrophilic-film coating on fins

The condensate water that forms on heat exchanger fins may adhere to the surface as droplets and cause bridging of the fin spacing, resulting in decreased heat transfer performance and increased air pressure drop. Adding a hydrophilic coating to heat exchanger fins gives them an affinity for water, which reduces the condensate layer thickness. This helps the water to flow down the fins and fall off the evaporator quickly, resulting in reduced air-side pressure drops and increased airflow rates across the heat exchanger.[80] Hydrophilic-film coating on heat exchanger fins have been shown to reduce air-side pressure drop 20 to 50 percent when operating with high-humidity room-side air. DOE is unaware of any publicly available data quantifying the energy efficiency improvements associated with hydrophilic-film coating on fins under normal room air conditioner operating conditions.

Spray condensate onto condenser coil

The condensate that forms on and drips off of the evaporator coil is collected in a condensate pan. Part of the pan is positioned near the condenser and is placed directly underneath the condenser fan. The condenser fan is equipped with a slinger ring, which is located at the fan blade tips and is able to collect and spray the condensate onto the condenser coil as the fan rotates. The spray provides evaporative cooling to enhance the performance of the condenser.

Microchannel heat exchangers

Unlike a conventional coil tube with an attached plate fin, microchannel heat exchangers have a rectangular aluminum cross-section containing several small channels (typically less than 1 millimeter across) through which refrigerant passes. Aluminum fins are brazed between the rectangular tubes. Microchannel can increase heat transfer while reducing pressure drop as compared with conventional coils. Microchannel heat exchangers generally weigh less and hold significantly less refrigerant than conventional heat exchangers.

Currently there are several manufacturers of microchannel heat exchangers. The technology was first used in automobile air conditioning systems, where it is used almost exclusively for condensers. Other air-conditioning applications are adopting the technology, particularly in applications requiring reduced size and weight. These include military environmental control units (ECUs), air-cooled chillers for commercial buildings, and some residential central air conditioning systems. However, microchannel heat exchangers have not yet been adopted by room air conditioner manufacturers. A key issue for use in room air conditioner applications is the much higher investment cost required for the equipment needed to fabricate these heat exchangers (*i.e.*, brazing ovens) as compared with equipment used for fabrication of conventional heat exchangers.

Microchannel heat exchangers have traditionally had difficulty in evaporator applications, because their geometry is less amenable to condensate removal than conventional heat exchangers. When installed with the headers oriented vertically, the horizontal flat fins between fin sections block gravity flow of condensate. Also, even distribution of expanded two-phase refrigerant into the many parallel flow paths through the tubes is challenging. While these issues can be alleviated by orienting the evaporator with the headers horizontal, such an orientation is undesirable for many applications.

Research has compared the performance of a window-mounted room air conditioner with microchannel condensers to a baseline system with a conventional finned-tube condenser. The results showed the heat transfer rates per unit core volume of the microchannel heat exchangers were 14 to 331 percent higher than the conventional finned-tube heat exchangers. However, the overall efficiencies of two systems using the microchannel condenser heat exchanger were 1 to 3 percent lower than the baseline system. The lower efficiencies attained by this work were believed to be due in part to the un-optimized condensate slinger ring and smaller subcooling of the microchannel systems. The results did show reductions in refrigerant charge, condenser core volume, and weight of 35, 55, and 35 percent, respectively, using microchannel condensers.[81]

Improved indoor blower and outdoor fan efficiency

The air delivery system of a room air conditioner consists of one motor driving two fans, the indoor blower (evaporator), and outdoor (condenser) fans. The evaporator blower is typically a centrifugal blower, while the condenser fan is a propeller-type fan with a slinger ring attached to it. As mentioned earlier, the slinger ring sprays condensate onto the condenser coil.

Improvements to the fan designs to improve air flow characteristics could increase the overall efficiency by decreasing the power demands for the fan motor.

Fans and blowers are generally molded plastic parts with fairly advanced geometries as compared with stamped sheet metal designs of the past. The condenser fan is mounted with reasonable clearance to the fan orifice, which is typically sheet metal which may have a formed bell mouth in the region of the fan blade tips. The evaporator blower is generally housed inside a Styrofoam enclosure which is shaped to provide smooth flow of air into and out of the blower. The Styrofoam doubles as thermal isolation between the indoor and outdoor sides of the unit.

Air system efficiency could possibly be improved through more advanced fan and blower design. It could also be improved by reducing the restrictions to air flow. However, the space limitations within room air conditioners make reduction of flow resistance difficult. Adjustments to the designs of the heat exchangers can affect air flow, as discussed in the sections addressing heat exchangers above.

Improved blower/fan motor efficiency

Room air conditioners primarily use permanent split capacitor (PSC) fan/blower motors. These motors range in efficiency from 45 to 70 percent. While larger motors are generally more efficient, there is a range of efficiency for any given power level.

Electric motors operate based on the interaction between a field magnet and a magnetic rotor. However, single-phase motors only produce a rotating magnetic field when the rotor is rotating, and simply powering the electromagnet is therefore not sufficient to start such a motor. One of the most significant differences between different types of single-phase motors is the way in which they handle start-up. In a PSC motor, a small start-up winding is present which is energized out of phase with the main winding. The start-up winding is electrically connected in parallel with the main winding and in series with a capacitor. At start-up, the interactions between the magnetic field generated by the start-up winding and that generated by the main winding induce rotation. As the capacitor charges, the current flowing through the start-up winding decreases, and the start-up winding becomes an auxiliary winding after the motor reaches running speed. Consequently, the current to the start-up winding is cut off once the capacitor is fully charged and the motor reaches steady-state speed. PSC motors are produced in large quantities and are relatively inexpensive.[82]

Permanent magnet motors have higher efficiencies than PSC motors. For the purposes of this report, they will be called brushless DC (BLDC) motors. They are also known as ECMs, brushless permanent magnet (BPM) motors, and electronically-commutated permanent magnet (ECPM) motors. BLDC motors are more efficient than PSC motors. BLDC motors convert single-phase AC input power into DC power and achieve the commutation required for operation of DC motors by electronic switching rather than through use of a conventional mechanical commutator. The commutation is coordinated through use of sensor technology that determines when the motor is at the proper angle for switching the power. BLDC motors have efficiencies approaching 80 percent.[83] However, BLDC motors can weigh more than PSC motors of the same shaft power, potentially necessitating a redesign of the room air conditioner chassis to accommodate the increased weight. In addition, BLDC motors are more expensive than PSC motors.

Improved compressor efficiency

Most room air conditioners are now made with hermetic rotary compressors. Rotary compressors have displaced reciprocating compressors, because they are smaller, weigh less, and have reduced noise and vibration. Compressors for room air conditioners traditionally used a hydrochlorofluorocarbon (HCFC) refrigerant, designated HCFC-22. Maximum rotary compressor efficiencies for HCFC-22 refrigerant range from 10.7 to 11.2 EER. However, due to the phaseout of HCFC-22 for new products that took place starting in 2010, room air conditioners have switched to R-410A refrigerant, which is a blend of hydrofluorocarbon (HFC) refrigerants that do not contain chlorine. The room air conditioner market has lagged central air conditioners in the transition to R-410A. Compressor manufacturers have developed rotary compressors for the new refrigerant, but the product lines initially available did not span the applicable capacities and efficiency levels for room air conditioners fully. Hence, while room air conditioner manufacturers may have had multiple compressor options of varying EER to consider in the design of a unit using HCFC-22, there may initially have been only one option with appropriate capacity for the design of a unit using R-410A. This compressor availability issue improved as 2010 arrived, and is expected to improve further. Also, the thermodynamic efficiency of R-410A is not as high as that of HCFC-22 at operating conditions typical for rating of room air conditioner performance.

Scroll compressors require high precision to produce their internal components and are typically found in higher-efficiency central air-conditioning systems. Scroll compressors compress gas in a fundamentally different manner from traditional compressors — between two spirals, one fixed and one orbiting. Scroll compressors EERs for HCFC-22 refrigerant range from 10.8 to 11.2 for the capacities of interest for larger room air conditioners. Scroll compressors are generally 1 to 2 inches taller than rotary compressors, and therefore are better suited for larger units.[84] Scroll compressors can be larger and heavier than their rotary counterparts. Thus, incorporating these compressors may require larger chassis sizes and bracing to accommodate the increased size and weight.

Switching Power Supplies

A potential area for standby power improvement for room air conditioners is the power supply on the control board. As with clothes dryers, a typical room air conditioner may use an unregulated plus regulated control board power supply, with voltage regulators stepping down the unregulated voltage(s) to the level(s) required by the control logic, display, and remote control sensor. As noted previously for clothes dryers, this approach results in a rugged power supply which is reliable, but typically has an efficiency of about 55 percent. The power supply accounts for the majority of the energy consumed by the control board in inactive mode. DOE's room air conditioner reverse engineering showed that the majority of the inspected units used this type of power supply.

Power supply efficiency may be improved, at higher cost and complexity, with the use of switching power supplies. For a complete discussion of switching power supply function and efficiency, see section 3.15.2.1 for the comparable clothes dryer technology option. Based on DOE's reverse engineering, described in chapter 5 of this TSD, DOE determined that room air conditioners with switching power supplies consume approximately 0.7 W in standby mode, a roughly 50 percent power savings as compared with standby power consumption with linear power supplies.

Two-speed, variable-speed, or modulating-capacity compressors

Most conventional single speed compressors run at a constant speed and vary their capacity by cycling on and off in response to the thermostat. The efficiency of systems using these compressors is typically lower than full-capacity efficiency at part load, due to off-cycle losses. Variable-speed compressors are typically implemented through the use of an electronic control that varies the input frequency of the power supply for the compressor motor. Variable-speed compressors enable modulation of the refrigeration-system cooling capacity, allowing the air conditioner to match the cooling load. This can improve efficiency by eliminating off-cycle losses and because, when operating with the lower mass flow at part load, the heat exchangers are more effective. There are non-energy advantages to variable-speed control, including quieter operation at low speeds, enhanced comfort by eliminating temperature fluctuations in the room, and potential for improved dehumidification.

The control of variable-speed compressors is accomplished through the use of electronic adjustable-speed drives (ASDs) at the motor. Because electronic ASDs require no drive-train in order to be coupled to the motor, they can be used with the sealed refrigeration systems used in room air conditioners. ASDs can be designed for use with induction motors or with permanent-magnet brushless motors. There are two inverter types that are applicable to induction motors typically used in room air conditioner compressors: voltage source (VSI) and pulse-width modulated voltage source (PWM) inverters. In either case, the input AC power supply is first converted to DC by using a solid-state rectifier. This DC signal is then converted to a variable-frequency AC waveform by the inverter and supplied to the motor. The speed of the motor is roughly proportional to the frequency.[85]

A recently developed method for modulating capacity in scroll compressors is intermittent discharge. This technology utilizes a pressure control system in which a solenoid valve opens, relieving the pressure on the back side of a piston. This spring-loaded piston is connected to the rotating scroll, and the scroll-piston system is then displaced once the backpressure is removed. This displacement disengages the scrolls, leaving the driveshaft free to rotate without any compression taking place. Modulating the time in which the scrolls are engaged allows capacity to be varied from 10 to 100 percent of maximum. Intermittent discharge technology, however, is only applicable to scroll compressors, and is a proprietary approach.[r]

There are no obvious technical barriers to use of variable-speed compressors in room air conditioners. ASDs have been demonstrated to perform well with both rotary and scroll compressors. The heat pump market in Japan is now dominated by split systems equipped with

[r] For more information, please visit www.digitalscroll.com/digitalweb/english/howitworks.htm

variable-speed rotary compressors. Based on an initial US market survey, a number of manufacturers offer split system air conditioners equipped with inverter systems using variable speed compressors. The most common motor used in this application is an induction motor. But the HVAC industry is now showing a strong interest in brushless permanent magnet motors due to their high efficiency.

As stated earlier, technology options that primarily improve efficiency on a seasonal basis will not demonstrate any efficiency improvements according to the current DOE test procedure which specified steady-state conditions. The greatest benefit of variable speed systems is to save energy on a seasonal basis. Because tests have not been performed to determine the amount of cycling in room air-conditioners, the potential magnitude of seasonal energy savings in room air units is not well understood. Research has demonstrated that energy savings from 15 to 40 percent are attainable in central air conditioning systems.[86,87,88] In the previous rulemaking, DOE estimated that the implementation of variable-speed compressors in room air-conditioners could achieve an energy savings of approximately 10 percent.[89] However, comments received from manufacturers subsequent to the Framework Document public meeting of this current rulemaking indicate that room air conditioners are typically purchased oversized relative to the conditioned space, indicating that they would operate in on/off mode and thus preclude the energy savings associated with variable-speed systems.

Thermostatic or electronic expansion valves

Manufacturer interviews and DOE's reverse engineering indicate that the capillary tube is the flow control device that is currently used by all room air conditioners. The capillary tube is a pressure-reducing device that consists of a small-diameter tube that connects the outlet of the condenser to the inlet of the evaporator. The very high pressure drop as refrigerant flows through the capillary allows the high and low pressures in the system to be maintained. Since it is a fixed device, the capillary tube provides optimum system operating parameters over a narrow range of operating conditions.

The thermostatic expansion valve (TXV) — a flow-control alternative to the capillary tube — is commonly used in higher-efficiency central air-conditioning systems. TXVs regulate the flow of liquid refrigerant entering the evaporator in response to the superheat of the refrigerant leaving it. TXVs can adapt better to changes in operating conditions, such as those due to variations in ambient temperature, which affect the condensing temperature. As a result, TXVs can control for optimum system operating parameters over a wider range of operating conditions, and can thus improve seasonal efficiency.

Electronic expansion valves (EEVs) are similar to TXVs, but they operate using electronic (microprocessor) control. The EEV uses a pulse motor, which rotates based on an electronic signal from a microcomputer determining the desired valve position from measured system parameters. While a TXV is limited due to its thermo-mechanical design, there is greater flexibility for operation of an EEV. Research has demonstrated that, when incorporated into air-conditioning systems using inverter-driven variable-speed compressors, EEVs improve seasonal energy efficiency beyond that of systems using conventional TXVs. As with variable speed compressors, the main benefit of electronic expansion valves is to improve efficiency on a seasonal basis. DOE is aware of a patent describing a room air conditioner using an electronic expansion valve[90] but is not aware of any publications describing prototype testing to evaluate the efficiency improvement potential of this technology.

Thermostatic cyclic controls

Remote thermostatic cyclic controls more accurately monitor room temperature than typical built-in thermostats. Research has been conducted to investigate the use of fuzzy logic controllers for HVAC applications. These controller types have been shown to improve the performance of HVAC systems over that of conventional controllers. Thermostatic controls could offer seasonal energy savings.

As with variable speed compressors and expansion valves, the DOE test procedure can only measure energy efficiency improvements based on steady-state conditions. In addition, no data were found or presented that indicated how the performance of room air conditioners could be enhanced with thermostatic cyclic controls.

Technologies Not Passed to the Screening Analysis

DOE identified the following technologies as potentially providing opportunity for energy savings. However, as described individually for each of the technologies, DOE determined that these technologies were not suitable for consideration for the engineering analysis because sufficient data are not available to demonstrate that the technologies save energy as compared to current products.

R-407C Refrigerant

R-407C is a blend of HFC refrigerants that could be considered for use in room air conditioners instead of R-410A. In response to stakeholder comments during the preliminary analysis phase, DOE conducted preliminary modeling of R-407C room air conditioner systems, using the MarkN analysis tool used for energy modeling.[s]

DOE conducted this R-407C assessment using five room air conditioner energy models developed as part of the engineering analysis. These energy models represent product classes 1, 3, and 5, all product classes with louvered sides and without reverse cycle, with varying capacities (5,000 Btu/h, 8,000 Btu/h, 12,000 Btu/h, 24,000 Btu/h, and 28,000 Btu/h). The development of energy models for these products is described in section 5.9.2.4 in chapter 5 of the TSD. DOE compared identical designs for these products, operating with both R-410A and R-407C. These designs represent drop-in of R-410A and/or R-407C in a product designed for HCFC-22. Figure 3.15.2 shows the modeling results of R-410A and R-407C with the MarkN model. In each product class, the efficiency of the R-407C system was notably lower than the

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[s] The MarkN energy model is discussed in chapter 5, "Engineering Analysis", of the TSD, in section 5.9.2.4.

respective R-410A system. These analyses don't definitively indicate that R-407C could not provide any efficiency benefit as compared to R-410A, because the systems were optimized for neither of these refrigerants for this analysis. However, they do provide an indication that R-407C does not provide clear improvement.

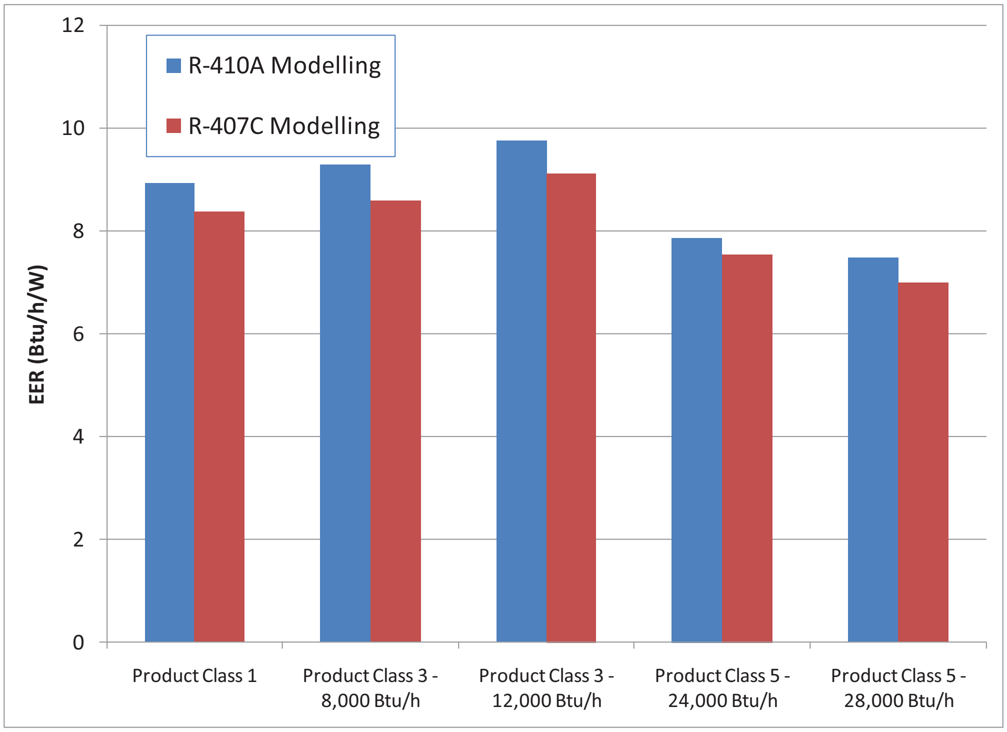

Figure 3.15.2. Modeling of R-407C compared to R-410A

The room air conditioning industry has switched to R-410A in response to EPA requirements banning use of HCFC-22 starting in 2010. 74 FR 66412, 66418 (December 15, 2009). Based on discussions with manufacturers during both preliminary analysis and final rule phase interviews, there was no indication that any manufacturers would instead consider use of R-407C refrigerant as a potentially more efficient option. DOE concluded that it is not realistic to expect the industry to transition away from R-410A in response to more stringent efficiency standards. Hence, DOE's analysis was based on industry's continued use of R-410A, and alternatives such as R-407C were not considered as design options.

Liquid-Line to Suction-Line Heat Exchangers

In response to stakeholder comments during the preliminary analysis phase, DOE investigated the use of suction-line heat exchangers (SLHX). These heat exchangers cool the refrigerant leaving the condenser (or leaving the subcooler, if the refrigeration circuit has a subcooler) by simultaneously warming the refrigerant vapor leaving the evaporator. This increases capacity, but also increases compressor power input, since the warmer refrigerant vapor returning to the compressor has greater volume. However, for some refrigerants, the technology can improve efficiency.

The preliminary phase comments of the California Investor-Owned Utilities (IOUs) cited a study conducted by the National Institute of Standards and Technology (NIST) investigating the use of LSHX.[t] This study reports an EER improvement using a SLHX of 1.0 percent for an outdoor temperature of 95 °F, which is used in the DOE energy test. These results were obtained in a modeling study using the NIST vapor-compression model CYCLE 11. There is no indication in the paper that the simulations address room air conditioners, since it does not mention outdoor air moisture content, which would be an important parameter affecting performance of room air conditioners. While the simulations show a potential for slight performance improvement, questions about the applicability of the assessment remain, because it is not clear that the simulations are applicable for room air conditioners and the because the results were not validated experimentally.

DOE notes that use of SLHX raises the temperatures of the incoming vapor to the compressor, which raises the temperature of the compressor. Warmer compressor temperature will generally reduce compressor lifetime, since heat-sensitive compressor components are designed for specified life when operating under specific conditions. Compressor suction temperatures are typically close to 65 ˚F in room air conditioners operating under DOE test conditions. This is also typically the highest allowable steady-operating suction temperature for R-410A rotary compressors, based on compressor specifications obtained from compressor vendors. A SLHX operating at close to 50% effectiveness (as analyzed in the NIST study) would raise suction temperature roughly 20 ˚F, thus significantly exceeding the specified limit.

During interviews conducted during the preliminary and final rule analysis, manufacturers did not indicate that SLHX could be used to improve system performance.

Because of concerns regarding impacts on product life and reliability, and the fact that manufacturers did not indicate that this technology can be used to improve efficiency, DOE did not consider SLHX as a design option in its engineering analysis.

3.15.3 Energy Efficiency

In preparation for the screening and engineering analyses, DOE gathered data on the energy efficiency of residential clothes dryers and room air conditioners currently available in the marketplace. This data is taken from databases maintained by a variety of regulatory agencies. While this section is not intended to provide a complete characterization of the energy efficiency of all appliances currently available and in use, it does provide an overview of the energy efficiency of each product covered by this rulemaking.

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[t] "Performance of R-22 and its Alternatives Working at High Outdoor Temperatures." Eighth International Refrigeration Conference at Purdue University, West Lafayette, IN – July 25-28, 2000 pp. 47-54

3.15.3.1 Residential Clothes Dryers

The CEC publishes a list of "certified" residential clothes dryers. Figure 3.15.3 through Figure 3.15.5 display the distribution of clothes dryers in the CEC database that are currently available on the market as a function of EF for electric standard and compact dryers, gas dryers. Each graph also shows the current federal energy conservation standard. All of the dryer models listed in the CEC database meet or are above the current standard level, if one exists for the product class. There are also no ventless clothes dryer models listed in the CEC database since there is no accepted way of rating the performance of such dryers.

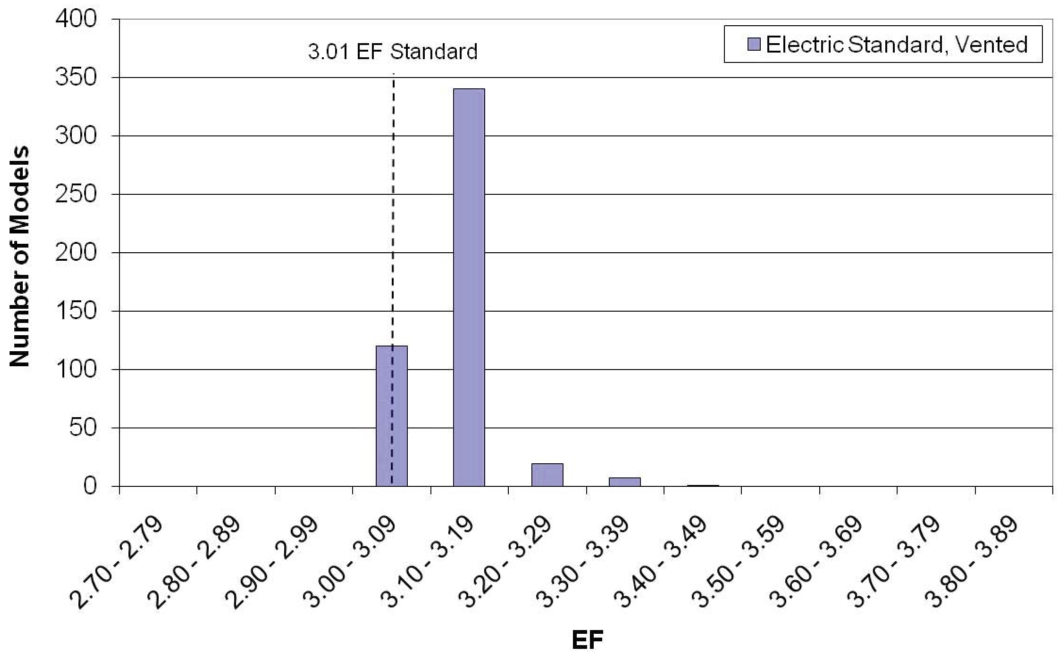

Figure 3.15.3 Electric Standard Capacity Clothes Dryers in the CEC Directory[91]

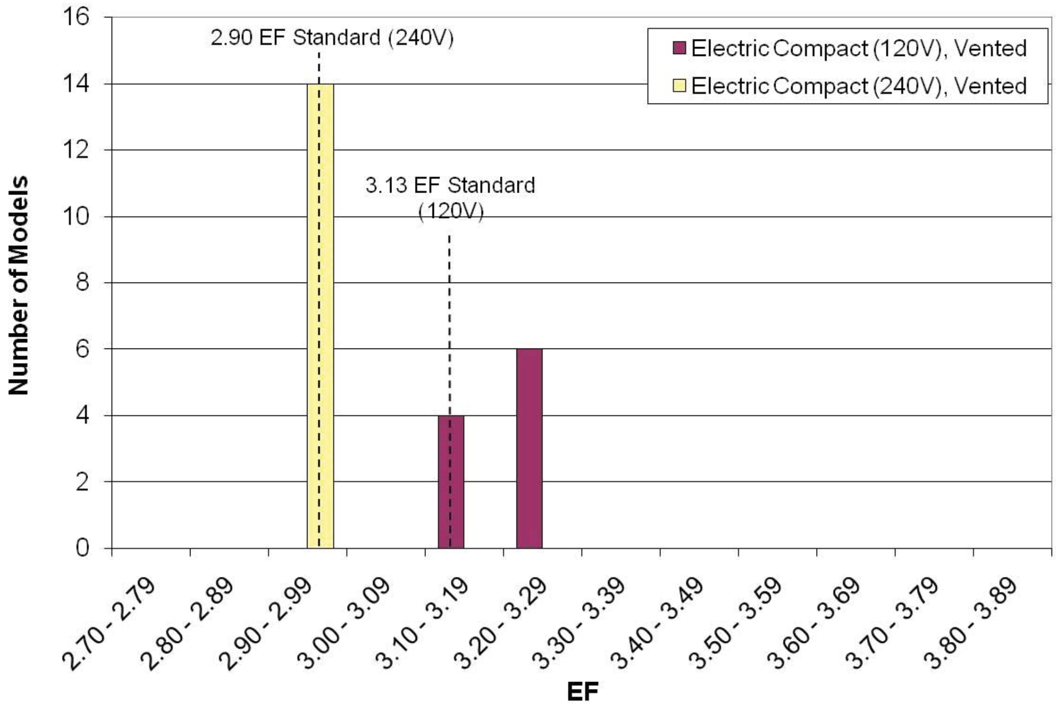

Figure 3.15.4 Electric Compact Capacity Clothes Dryers in the CEC Directory[92]

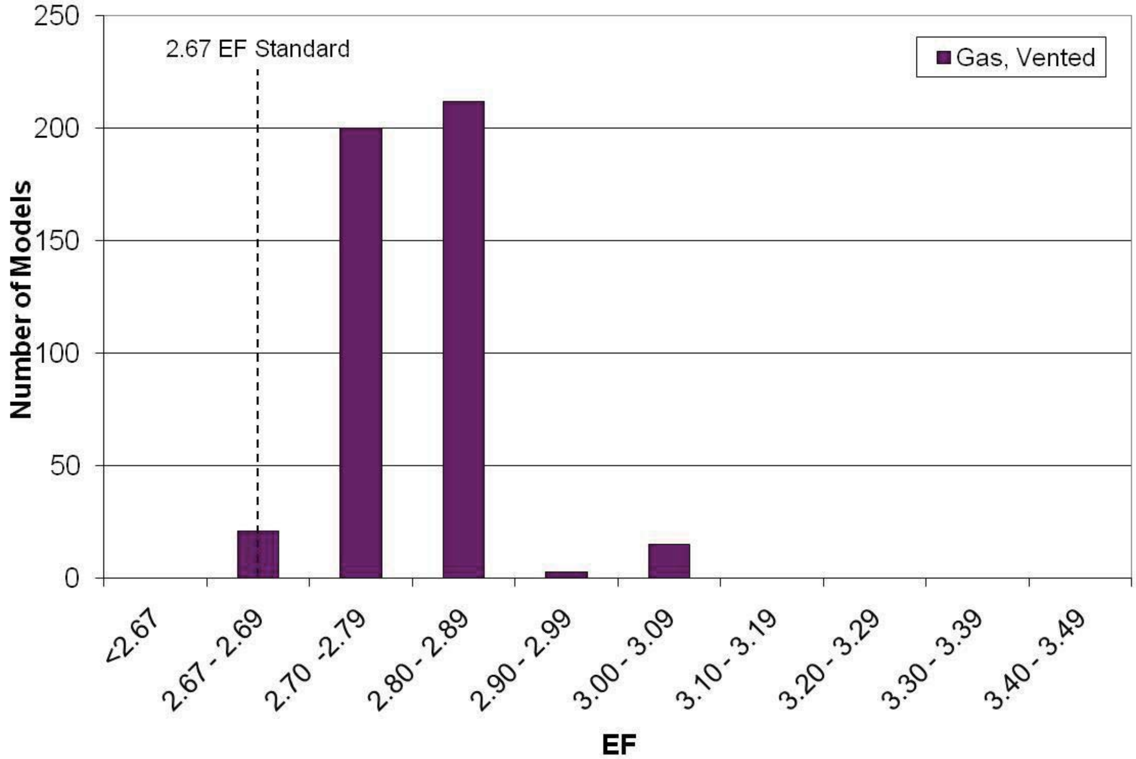

Figure 3.15.5 Gas Clothes Dryers in the CEC Directory[93]

AHAM submitted market share efficiency data for residential clothes dryers. Table 3.15.4 and Table 3.15.5 present the market share efficiency data for electric standard and gas dryers, respectively. AHAM noted that, in order to maintain confidentiality, market share for electric standard dryers between EF of 3.20 and 3.29 were incorporated into the EF range between 3.10 and 3.19. Similarly, market share for gas clothes dryers with an EF > 2.94 was incorporated into the EF > 2.85 efficiency bin.

Table 3.15.4 Residential Clothes Dryer Market Share Efficiency Data for Electric Standard Dryers[94]

EF	Market Share *(%)*	
	2005	**2006**
3.01 – 3.09	26	33
3.10 – 3.29	74	67

Table 3.15.5 Residential Clothes Dryer Market Share Efficiency Data for Gas Dryers[95]

EF	Market Share *(%)*	
	2005	**2006**
2.67 – 2.74	25	28
2.75 – 2.84	42	44
> 2.85	32	27

3.15.3.2 Room Air Conditioners

Although not completely representative of the entire current room air conditioner market, CEC, ENERGY STAR[u] and AHAM publish lists of "certified" room air conditioners. The AHAM Room Air Conditioner Certification Program verifies the cooling and heating capacity rating, amperes, and EER of each listed room air conditioner as tested by an independent laboratory.[v] DOE consolidated the three databases and reviewed all of the listed room air conditioners, searching websites of the manufacturers and retailers to verify whether the products are still active. DOE conducted this investigation in August 2008.

Figure 3.15.6 through Figure 3.15.9 show the EER versus the capacity of each room air conditioner listed in the consolidated database. Each graph illustrates the current federal energy conservation standard, which became effective on October 1, 2000. The screening of products which are no longer available removed many old products, but some of the products still had reported EER below the current federal standards. These may have erroneous EER listings, or have model numbers identical to updated products. In any case the exhaustive screening of the products in the databases clearly was not sufficiently thorough to eliminate all outdated entries.

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[u] For more information, please visit www.energystar.gov.

[v] For more information, please visit www.aham.org.

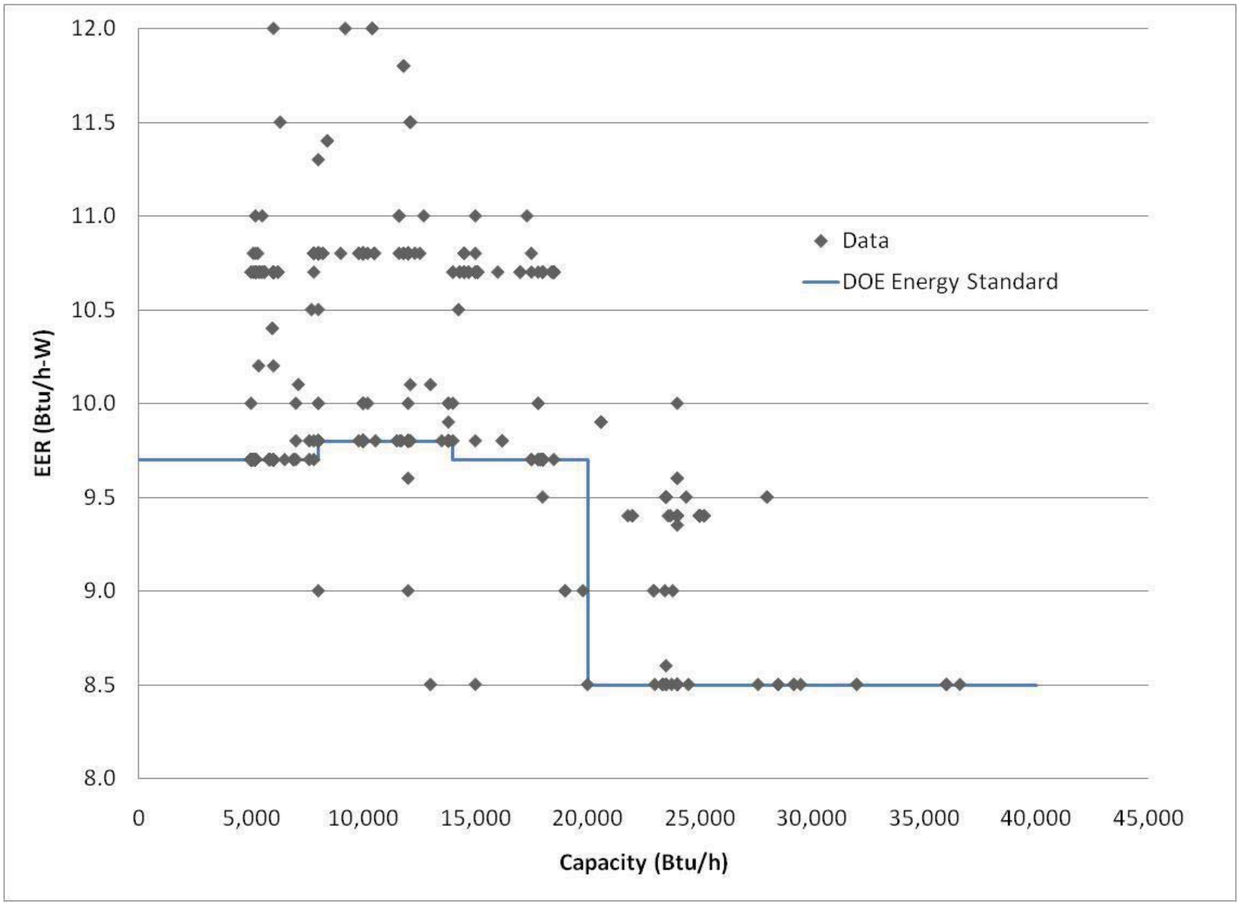

Figure 3.15.6 CEC, AHAM, and ENERGY STAR Certified Room Air Conditioners without Reverse Cycle and with Louvered Sides (Product Classes 1–5) [96, 97, 98]

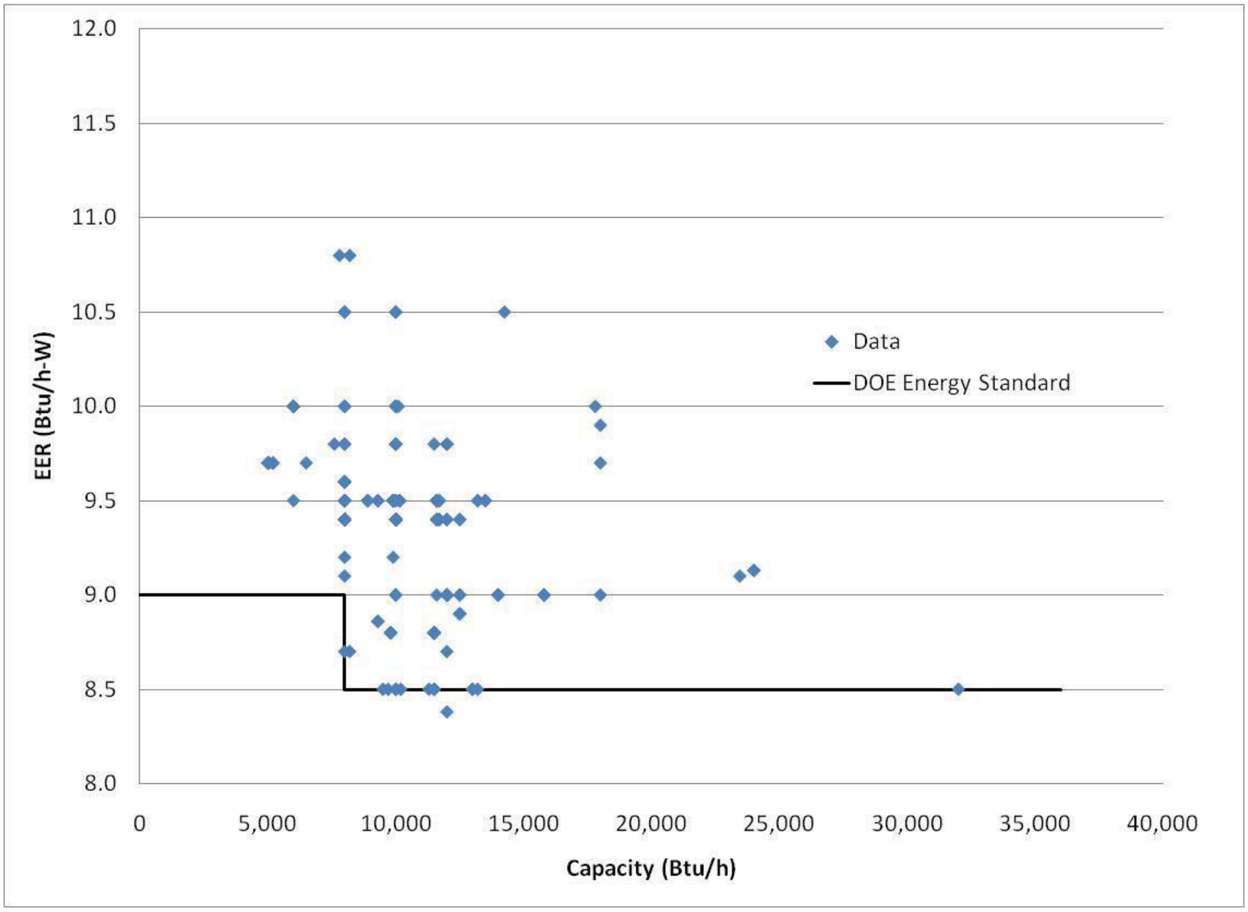

Figure 3.15.7 CEC, AHAM, and ENERGY STAR Certified Room Air Conditioners without Reverse Cycle and without Louvered Sides (Product Classes 6–10)[99, 100, 101]

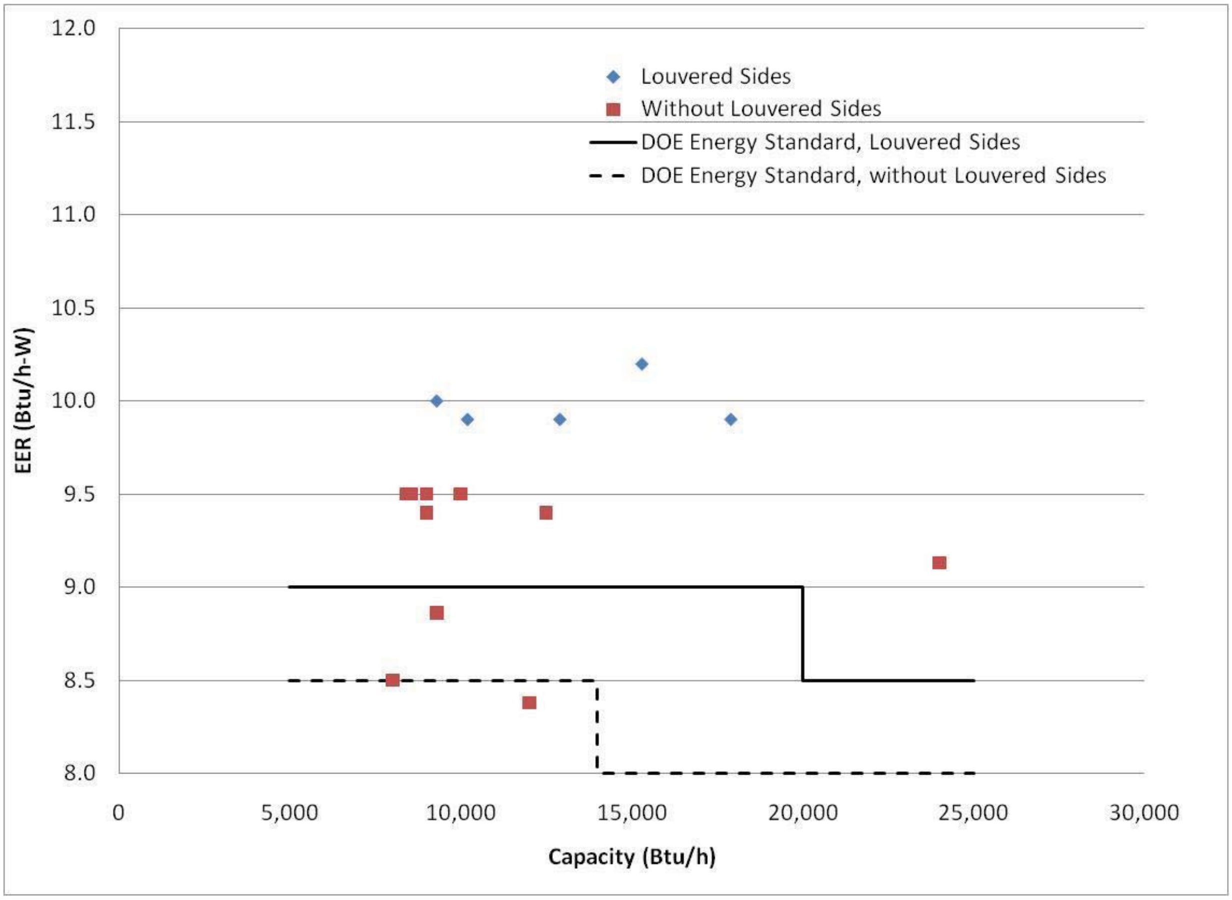

Figure 3.15.8 CEC, AHAM, and ENERGY STAR Certified Room Air Conditioners with Reverse Cycle (Product Classes 11–14)[102, 103, 104]

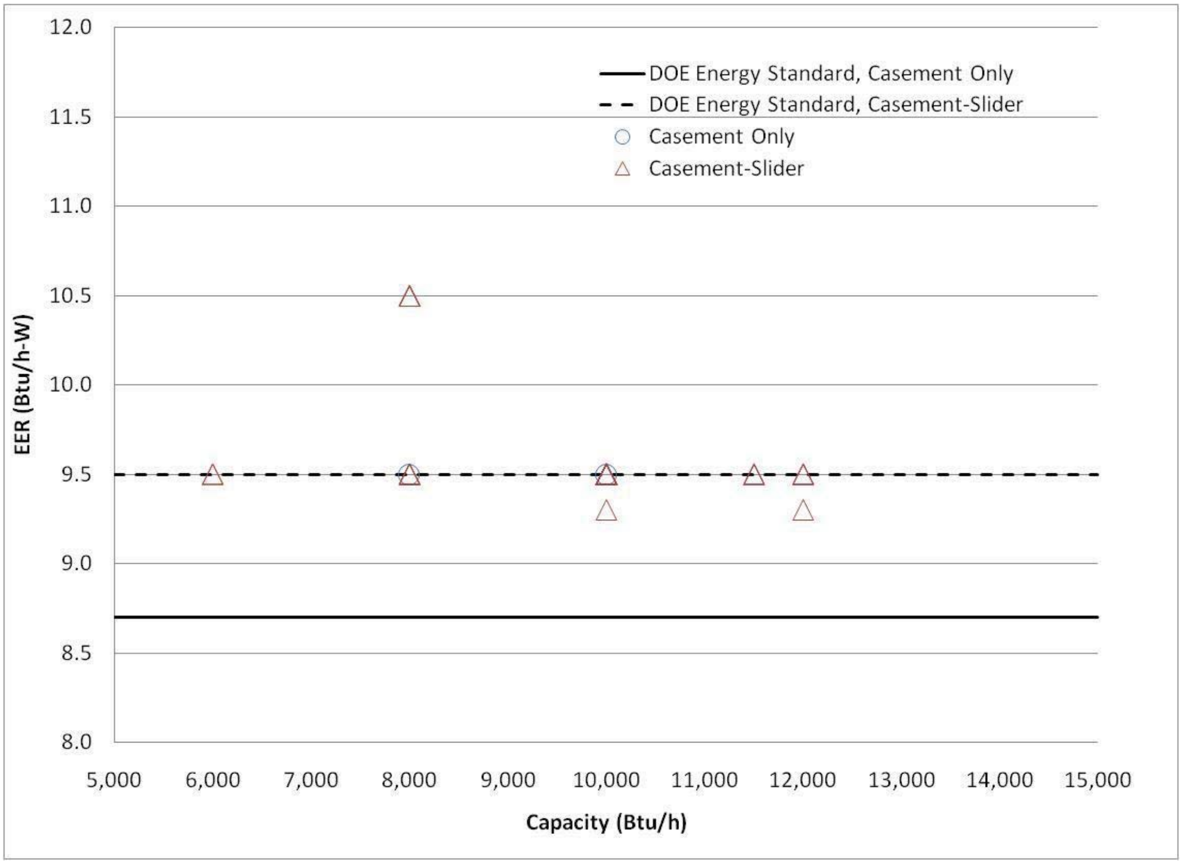

Figure 3.15.9 CEC, AHAM, and ENERGY STAR Certified Room Air Conditioners Casement-Only and Casement-Slider (Product Classes 15, 16) [105, 106, 107]

Figure 3.15.10 shows the distribution of the models listed in the screened database for each product class. Nearly 70 percent of the products are room air conditioner models without reverse cycle and with louvered sides (product classes 1 through 5). In addition, there are a high number of models in product class 8, room air conditioners without reverse cycle, without louvered sides, and a capacity between 8,000 and 13,999 Btu/h. Also of note, there are no models in product class 13 (with reverse cycle, with louvered sides, capacity greater than 120,000 Btu/h). During individual manufacturer interviews, manufacturers confirmed that product classes 1, 2, 3, 4, 5, and 8 make up the vast majority of room air conditioner shipments.

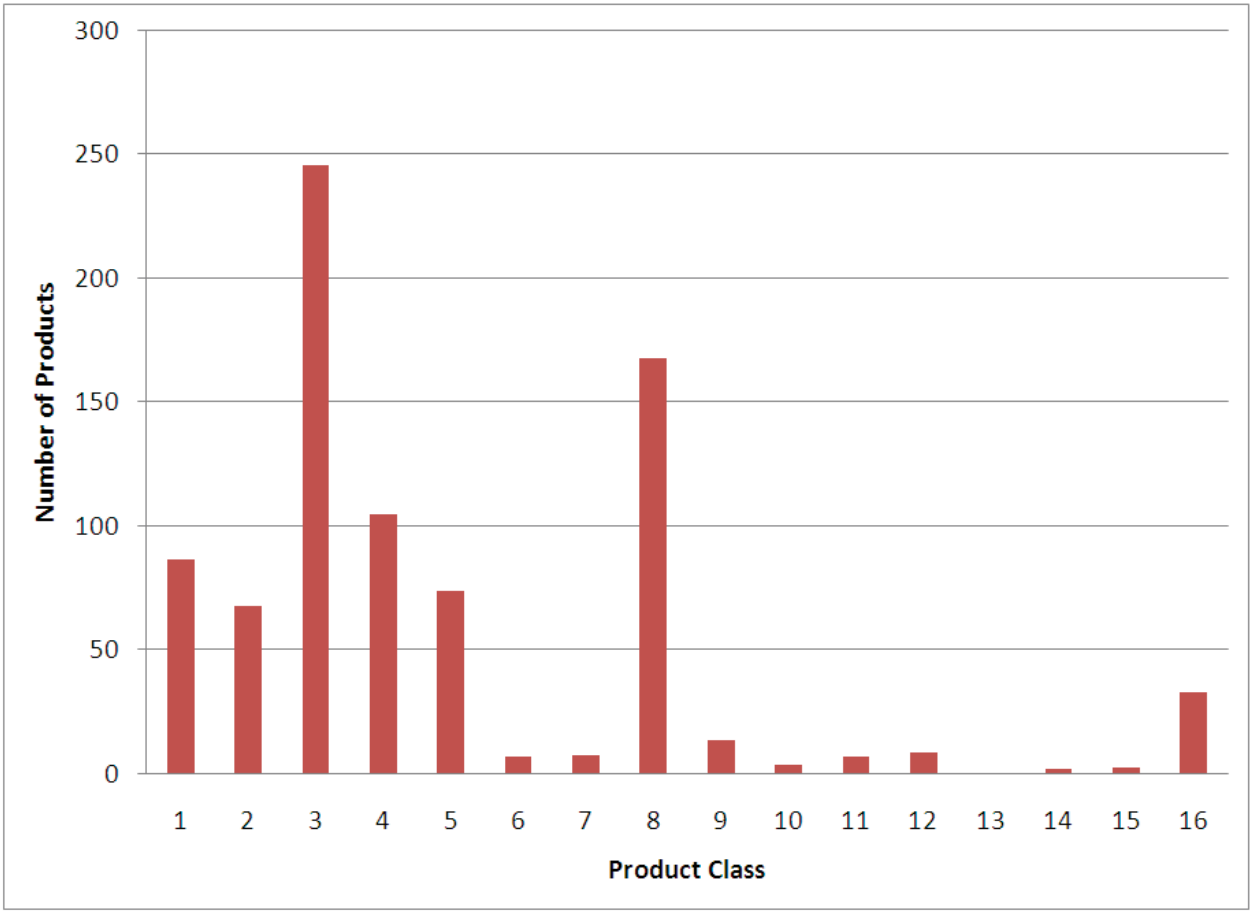

Figure 3.15.10 Distribution of Room Air Conditioner Models in the CEC, AHAM, and ENERGY STAR Databases[108, 109, 110]

DOE during the final rule phase conducted another investigation of the ENERGY-STAR Database, manufacturer websites, and vendor websites to assemble information on newly available R-410A units. Figure 3.15.11 through Figure 3.15.12 show the EER versus the capacity of each room air conditioner found in this investigation. Each graph illustrates the current federal energy conservation standard, which became effective on October 1, 2000. Some of the products still had reported EER below the current federal standards. These may have erroneous EER listings, are mislabeled, or have model numbers identical to updated products. DOE completed this investigation in May 2010.

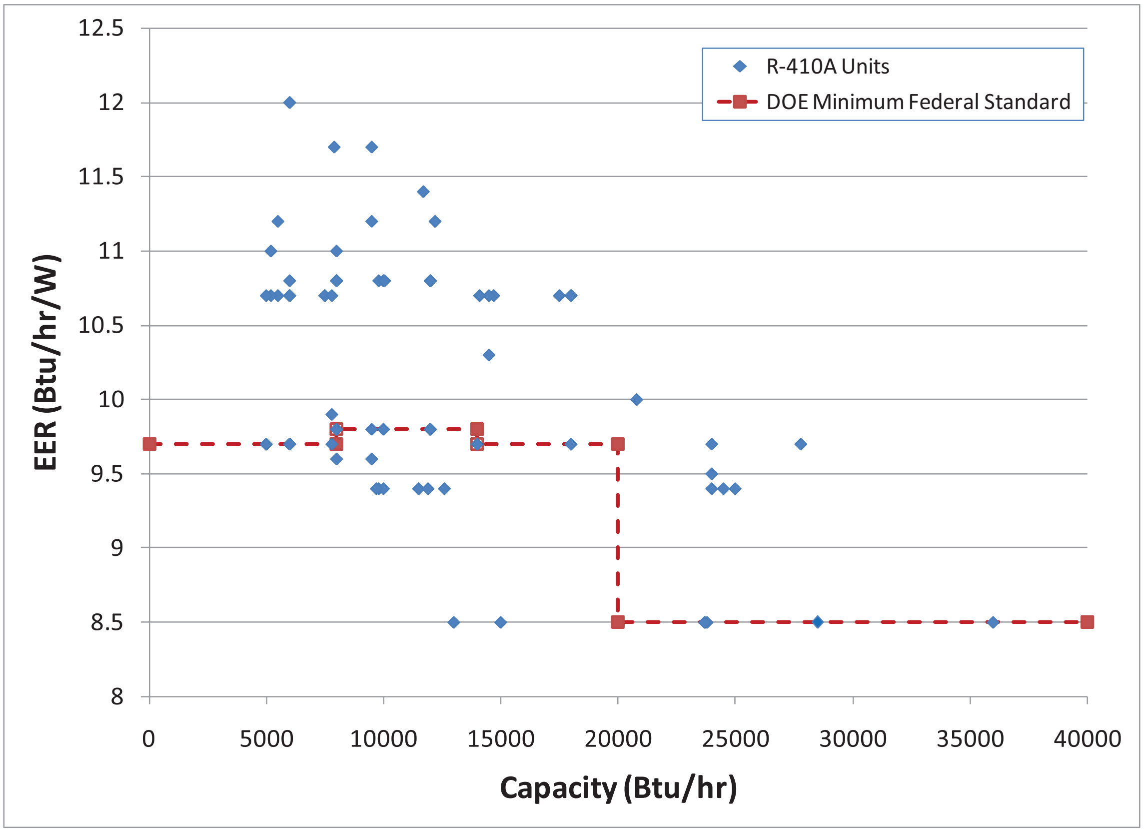

Figure 3.15.11. R-410A Room Air Conditioners without Reverse Cycle and with Louvered Sides (Product Classes 1–5)

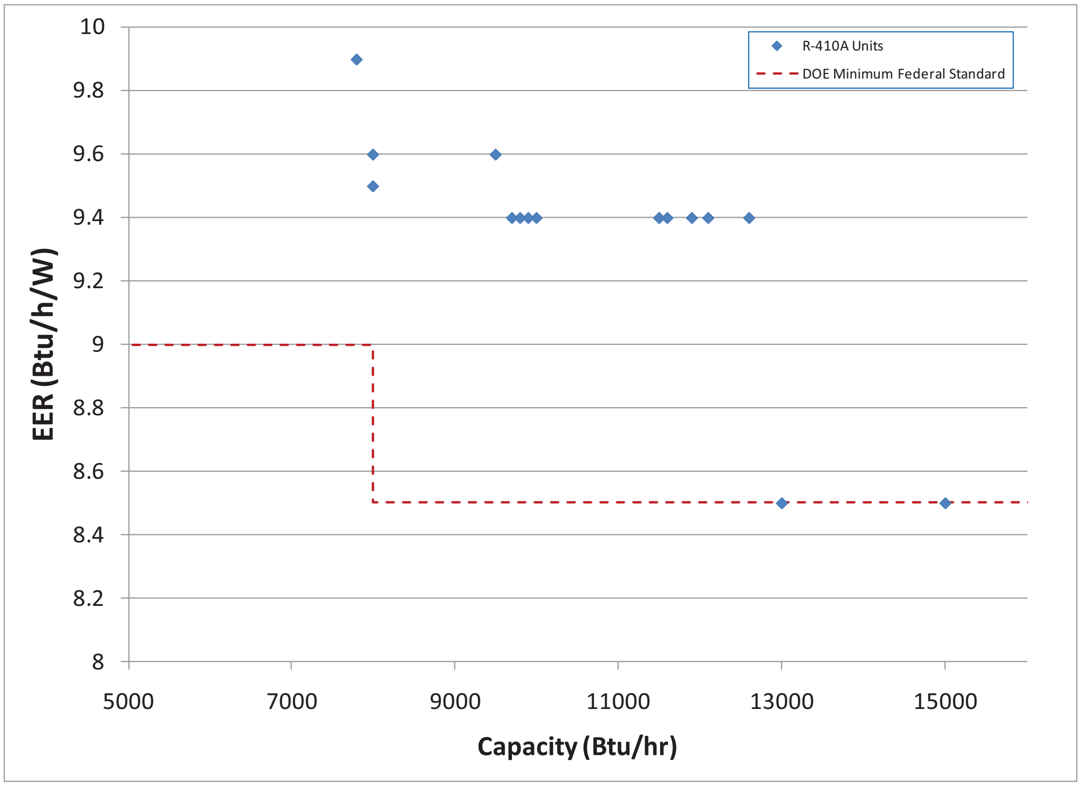

Figure 3.15.12. R-410A Room Air Conditioners without Reverse Cycle and with Louvered Sides (Product Classes 1–5)

Investigation of Max-Tech Units

During the preliminary analysis public meeting, DOE requested comment on the efficiency levels chosen by DOE. DOE identified products with an EER of 12.0 as the highest efficiency products available on the market. Several stakeholders commented that DOE should update its analysis to include all current ENERGY STAR and max-tech units on the market. In particular, stakeholders indicated that the CEC and the ENERY-STAR databases listed products with higher efficiency levels than those considered by DOE.

DOE is aware that the ENERGY STAR and CEC databases have listed products that exceed the max-tech EER of 12.0 that DOE identified in the preliminary analysis. Table 3.15.6 below, shows products listed at 12.0 EER or higher in one or both of these databases. Some of these products were noted specifically in stakeholder comments.

Table 3.15.6 RAC Models of Interest for Max-Tech Analysis, as Listed in the ENERGY-STAR and CEC Listings

Brand	Model	Listed EER	Source

			CEC	ENERGY STAR
Climette	CH1826A	13.8	✓	
Comfort-Aire	REC-183	13.8	✓	
Fedders	AED18E7DG	13.8	✓	
Maytag	MED18E7A	13.8	✓	
Fedders	A7Q06F2A	13.4	✓	
Turbo Air	TAS-09EH	13.5		✓
Turbo Air	TAS-12EH	13.0		✓
Turbo Air	TAS-18EH	13.0		✓
Friedrich	SS10M10	12.0	✓	✓
Friedrich	YS09L10	12.0	✓	✓
Friedrich	SS10L10	12.0	✓	✓
Friedrich	XQ06M10	12.0	✓	✓
Friedrich	SS12M10	12.0	✓	
Haier	ESAD4066	12.0		✓

DOE investigation of these products indicates that none of the products listed with EER higher than 12.0 represent valid RAC ratings, and that some of the products rated at an EER of 12.0 are also invalid representations. The first five products in the table are listed with much lower EER ratings in Natural Resources Canada (NRCan) database[w]. Table 3.15.7 below contains the NRCan ratings of these products.

Table 3.15.7 Selected Product Ratings in NRCan Directory

Brand	Model No.	Listed EER in NRCan Database
Climette	CH1826A	9.7
Comfort-Aire	REC-183	9.7
Fedders	AED18E7DG	9.8
Maytag	MED18E7A	9.8
Fedders	A7Q06F2A	10.7

The three Turbo-Air products are ductless mini-split products (as identified by the manufacturer's website[x]), not room air conditioners. The Friedrich SS12M10 has been rerated at

[w] (1) "EnerGuide for Equipment – EnerGuide Room Air Conditioner Directory 2002". Natural Resources Canada, Office of Energy Efficiency.2002; (2) Room Air Conditioner Model Listing. "EnerGuide Room Air Conditioner Directory 2004" http://oee.nrcan.gc.ca/.

[x] Product Specifications and Descriptions for Turbo Air Products TAS-09EH, TAS-12EH, TAS-18EH. Please see more information at www.turboairinc.net/productspecs/productspecs.html

lower than 12.0 EER[y], and the validity of the 12.0 rating of the Haier ESAD4066 is also in question.

In particular, Consumer Reports published an article in October 2008[z] in which it reported on test results indicating that the Haier ESAD4066's efficiency was not 12 EER. DOE's analysis of this unit using the Mark N energy model (discussed in chapter 5 of this TSD), showed that matching this performance level with the energy model required making some input assumptions that DOE considers unlikely, particularly for the condenser air flow rate.

Consequently, DOE concludes that its identification of a ma- tech available level no higher than 12.0 EER is valid, given the information available.

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